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TEXT-BOOK

OF

GEOLOGY

FOR SCHOOLS AND COLLEGES.

BY

H. ALLEYNE NICHOLSON,

M.D., D.Sc., M.A., Ph.D., F.R.S.E., F.G.S., Etc.,

PROFESSOR OF NATURAL HISTORY AND BOTANY IN UNIVERSITY COLLEGE, TORONTO; FORMERLY LECTURER ON NATURAL HISTORY IN THE MEDICAL SCHOOL OF EDINBURGH; AUTHOR OF "MANUAL OF ZOOLOGY FOR THE USE OF STUDENTS," "TEXT-BOOK OF GEOLOGY FOR SCHOOLS AND COLLEGES," "GEOLOGY OF CUMBERLAND AND WESTMORELAND," ETC., ETC.

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PREFACE.

The object of the present work is to present to the learner the leading principles and facts of geological science in as brief a compass as is compatible with clearness and accuracy. No science stands less alone, or is less independent of the other sciences, than Geology. Its foundation, as a science, is upon Physical Geography, and this subject has, therefore, been treated in the earlier portion of this work as fully as space would allow. No adequate knowledge, again, of the facts and generalizations of Palæontology can be acquired without some previous acquaintance with Zoology and Botany, the former more especially. A brief outline of the classification of the animal kingdom has, therefore, been here introduced; but the progress of the learner would be much facilitated by a more extensive study of Natural History than can possibly be presented in a work primarily devoted to Geology.

Palæontology, however, is to such an extent an independent science, and embraces such an extended area, that it can only be properly handled in a special treatise; and such a work is now in course of preparation by the author.

As to the plan of the work, it is sufficient to state that it is not based primarily upon American geology. Many important formations are not represented at all, or only in a very incomplete form, in America; while the *types* of the great geological formations are at present to be sought for in

Europe. The author is far from saying that there is any reason in Nature why this should be so; but the vast American Continent has as yet been very imperfectly explored; and there can be no question but that for many years to come European names and European types will hold their ground in geological literature. At the same time, the leading facts of American geology are in all cases stated, and in this connection the author feels bound to acknowledge the obligations which he is under to the works of Profs. Hall and Dana.

Most of the illustrations of the work have been supplied by the publishers from Sir Charles Lyell's classical treatise, the "Elements of Geology." The remainder have been drawn upon the wood by the author, and their source, where not original, is acknowledged in the text.

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GEOLOGY.

PART I.

PHYSICAL GEOGRAPHY.

CHAPTER I.

GEOLOGY (Gr. *ge*, the earth; *logos*, discourse) is the science which is concerned with the investigation of the materials which compose the earth, the manner in which these materials have been arranged, and the causes and mode of origin of these arrangements. The forms, properties, chemical composition, and local distribution of the materials which compose the crust of the earth, constitute the separate science of *Mineralogy*, which is, indeed, closely related to Geology, but which, nevertheless, is not essential to the study of the latter science. A limited knowledge, however, of Mineralogy is essential to a due comprehension of the phenomena of Geology, and such details as are thus requisite will be introduced in their proper place. *Palæontology* (Gr. *palaios*, ancient; *onta*, beings; *logos*, discourse) is a branch of Geology which treats of the past life of the globe and is concerned with those animals and plants which—as will be seen hereafter—have peopled the earth at successive periods, and have died out, to be replaced by others different in their character and structure. Here, therefore, Geology comes closely in contact with the sciences of Zoology and Botany, the sciences which treat of the various animals and plants which inhabit the earth at the present day. Palæontology, in fact, is nothing more or less than the Zoology and Botany of the past, and it is only especially connected with Geology in so far that by its study the observer is enabled to determine the historical succession of the materials which compose the globe. For the study of

Palæontology, some knowledge of the fundamental facts of Zoology and Botany is requisite, and an outline of some of these necessary facts will be subsequently given. *Physical Geography*, finally, comprises a knowledge of the figure and motion of the earth, of the composition, form, and distribution of the dry land, and of the forces which tend to modify its surface, of the character and distribution of the rivers and lakes which are placed on the land-masses, of the sea and atmosphere, and lastly, of the animal and vegetable life of different portions of the surface of the earth. Modern Geology rests, as a science, upon Physical Geography; and it is absolutely necessary that the student should acquire some knowledge of the fundamental facts of the latter science, as a preliminary to his commencing the study of the former. It is hardly necessary, however, to say that only the leading facts of Physical Geography can be touched upon here, in the very briefest manner, and only so far as they have a direct bearing upon the study of Geology. The points which require to be alluded to in this connection are, the form and planetary relations of the earth, the distribution of the dry land, and the agencies which tend to alter the characters of the earth's surface, especially the effects produced by rivers, ice, the atmosphere, and volcanoes.

Planetary Relations of the Earth.—The earth is one of the smaller of the planets which compose our system. It performs an annual revolution round the sun, in an elliptical orbit, at a mean distance of 95,000,000 miles. It also rotates in twenty-four hours about its own axis, this axis being inclined a little more than twenty-three degrees to the plane of its orbit. The moon is a satellite of the earth, revolving round it at a mean distance of 240,000 miles, and causing by its attraction certain terrestrial phenomena, of which the most important are the tides.

Figure and Dimensions of the Earth.—Astronomy teaches us that the earth has the form of what is technically called an "oblate spheroid." That is to say, it is not a perfect sphere or globe, all the diameters of which are equal; but it is flattened at the poles, like an orange, one diameter being longer than the other. The earth revolves about an imaginary axis, the two extremities of which constitute the poles—the North pole and the South pole. This, the polar axis of the earth, is, roughly speaking, 7,900 miles in length; while the equatorial or greatest diameter of the earth is 7,926 miles in length, exceeding the polar diameter by 26 miles.

The earth, therefore, is flattened at the poles, and bulges out at the equator.

That the earth, being such an oblate spheroid, with unequal axes, should revolve about its shortest axis is in obedience to well-known mechanical laws. Whether the earth has ever revolved about an axis different to its present one, or ever will do so, we do not know. As things stand, however, the earth's circumference at the equator is greater by some eighty-three miles than its circumference at the poles, and it is, therefore, practically in the condition of a sphere revolving on its shortest axis, and having a thick belt surrounding it in a plane perpendicular to the axis of rotation. Any disturbing force applied to the earth, with a tendency to alter its present axis of rotation, would have to overcome the excess of centrifugal force residing in the matter of this equatorial belt. This excess of centrifugal force is so enormous in amount that we may safely say we know of no force capable at the present day of effecting this change.

It is worthy of notice that the present form of the earth —the form, namely, of an oblate spheroid—is precisely the form which any body composed of fluid or semi-fluid substances would tend to assume, if it were set free in space after a preliminary movement of revolution had been imparted to it. In other words, the centrifugal force developed by the rotation would tend to accumulate the component particles of such a body along a zone lying at right angles to its axis of revolution. Any revolving body, of whatever original form, the particles of which are free to move, would ultimately assume the form of an oblate spheroid, revolving upon its shortest axis, and having its longest diameter at right angles to its axis of revolution. The present figure of the earth is, therefore, a strong argument in favor of the belief that the whole earth was at one time composed of melted materials, the particles of which were free to move in any direction toward which they might be impelled.

Primitive Condition of the Earth.—With regard to the original and primitive state of the earth, it is sufficient to state that all known facts support the theory that the earth has been, and is still, a gradually-cooling body. Upon this theory, the materials composing the earth were at one time in a state of vapor or gas, in which condition, of course, they would occupy enormously more space than they do at present. As the loss of temperature went on, the gaseous matters of the primitive earth would radiate their heat from the periphery, and would contract and ultimately become fluid. Finally, as the cooling process proceeded further and further, solidification would at last commence, either at the surface, or at the centre, or at both simultaneously. This is certainly to

a great extent a mere theory, but it is supported by two facts: One of these is the fact that the present form of the earth is exactly that which it would have assumed supposing it to have been formerly fluid or semi-fluid, and to have been revolving at its present velocity. The second of these is the undoubted high temperature of parts, at any rate, of the interior of the earth at the present day; and here we get upon tolerably firm ground.

Internal Temperature of the Earth.—As to the present temperature of the interior of the globe, the following facts enable us to come to some definite conclusion:

1. The phenomena exhibited at the present day—to be spoken of more particularly hereafter—prove beyond a doubt that large portions, at any rate, of the interior of the earth are in a state of complete fluidity, the fusion being the result of heat. At present the traces of direct volcanic action are only partially distributed over the globe; but we have ample and abundant proofs that volcanic action has taken place everywhere over the earth's surface at some time or other. Further, the universal presence at the surface of rocks which can be shown to have been originally melted and fluid, is quite sufficient proof that there has always existed—as there still exists—in the interior of the earth some powerful and general source of heat.

2. It is well known that the heating effect of the sun's rays upon the soil extends to but a very limited depth below the surface, and that a point is soon reached at which no perceptible effect is produced by any external source of heat. Nevertheless, it has been shown, as the result of direct experiment and observation, that there is a gradual and tolerably regular increase of heat as we recede from the surface of the earth and approach its centre. The exact ratio of this increase of temperature does not appear to be absolutely constant, but some increase there always is. In the case of mines, the ordinary rise of temperature, as we descend, is usually stated to be 1° Fahrenheit for every fifty or sixty feet of descent, after the first hundred. It is probable, however, that this increase would be found to be much more rapid than this at great depths. The same fact, and pretty nearly the same rate of increase, is shown by the phenomena of artesian wells, in which the water always comes from great depths, and always has a temperature considerably higher than the air. In the same way, such natural hot springs as are known to us, are either in the neighborhood of volcanoes, or can generally be

shown to be situated on lines of "fault," i. e., on the line of great cracks or fissures which penetrate through the crust of the earth to a greater or less depth.

3. Whenever we can study at the surface rocks which can be shown by geological evidence to have been formerly buried at great depths in the earth, these show unmistakable marks of having been subjected to the action of heat.

The above are the chief direct proofs of the internal heat of the globe, but there is other equally forcible evidence to be drawn indirectly from the *mean density* or weight of the earth. By numerous experiments it has been shown that the entire earth has a mean density or specific gravity of between *five* and *six*. That is to say, the earth is in the same condition as regards its density, as an imaginary globe would be of the same size, and composed throughout of a simple homogeneous substance weighing between five and six times as much as water. The earth, however, is not homogeneous, composed of one uniform substance, but heterogeneous, composed of different materials having different densities. Taking the average of the rocks which compose the crust of the earth, we find their *average* density to be only 2.5 to 3.0. The mean density, therefore, of the earth, is at least twice what it ought to be if it were made of any known rock, as that rock appears at the surface. At first sight, it might be thought that this would prove the presence in the interior of the earth of some materials much heavier than ordinary rocks, such as the metals. And this would be so, if the effect of gravity were left out of consideration. The earth is truly twice as heavy as it would be if it were entirely composed of any known rock, *as that rock appears at the surface.* Say the earth were composed of granite, which weighs about 2.5, and which represents, therefore, the average weight of rocks. Granite weighs about two and a half times as much as water at the surface of the earth, but by the effects of gravity, as we recede from the surface, its density would gradually go on increasing, till at the centre of the earth its density would be about eight times greater than at the surface, or at least twenty times as heavy as water, supposing the ratio of compression produced by gravity to be uniformly the same from the surface to the centre of the earth. If, therefore, the earth were conceived to be a homogeneous globe of granite, it would have a much *higher* mean density than only five or six. It would have a mean density of at least ten or twelve.

Seeing, then, that as a matter of fact the mean density of the earth is no more than about *five* (accurately 5.675), we have to look for some force which could counteract this compressing effect of gravity, and could prevent this regular increase of density in passing from the surface to the centre. We know of no other force capable of effecting this except the expansive power of *heat*, so that what is learned in this way fully corroborates what we are taught by direct observation.

Question as to the Fluidity of the Interior of the Earth.—The general belief as to the condition of the globe at present is that it consists of a cool, non-conducting *crust* or external envelope surrounding a highly-heated interior, and now the question arises, In what condition is that interior?

If we take 1° Fahrenheit for every 90 feet of descent as

the average increase of temperature, as we recede from the surface of the earth and approach its centre, then, at a depth of 90 miles below the surface, we should everywhere come down to a region in which the temperature would be about 5,000° Fahr. Now, all known rocks melt at about 2,000°, and platinum, one of the most refractory of metals, fuses at a little over 3,000°. At a depth, therefore, of about fifty miles below the surface, we should have all the materials which compose the crust of the earth in a state of fusion. At a still greater depth, supposing the law of increased temperature to hold good, all these melted substances would be further reduced to a state of vapor or gas. The condition, therefore, of the earth would be that of a hollow sphere, gaseous at its centre, with intermediate zones of fluid or pasty matter, and with a solid outer envelope or crust. This supposition, however, overlooks the effect of gravity, and could only be exactly correct supposing gravity to be wanting.

It is well known that, as a general rule, the effect of pressure is to raise the fusing-point of any material. If a given body would melt at the surface of the earth at a given temperature, it would require a much higher temperature to melt it if it were exposed to pressure; as it would be if removed nearer to the centre of the earth. Consequently, though the condition of the interior of the earth may well be as described above, the actual depth at which these changes occur will certainly be greater than is indicated by the mere law of the increase of temperature in descending below the surface.

In what exact ratio, and to what exact extent, the pressure of gravity interferes with the fusion of the interior of the earth, we do not know; but that it must so interfere is certain. The phenomena of volcanoes, however, prove that, in certain localities and at certain times, at any rate, melted matter is to be found at no great depth below the surface of the earth.

Upon the whole, then, it would appear safe to conclude that the earth consists of a, comparatively speaking, thin skin or solid crust surrounding a more or less completely fluid interior.

Surface of the Earth.—When we come to consider the surface of the earth, the first and most obvious fact which strikes us is, that it consists partially of dry land and partially of water. This fact is so obvious that we never ask ourselves why this should be so, but in reality it is a circumstance requiring explanation. It is quite conceivable that the surface of the earth might have been perfectly level, completely cov-

ered by water, and exhibiting no dry land. As it is, we not only have dry land, rising in some instances to over 29,000 feet above the sea-level, but we know that depressions fully as deep, and probably much deeper, exist below the level of the sea. If the crust of the earth had been always absolutely immovable, and were so now, no such state of affairs would be found, since, as we shall see later on, every thing above the sea would by this time have been reduced to below the level of the lowest tides.

The origin and existence, then, of dry land is only to be explained upon the supposition that the crust of the earth is not immovable, but that it is liable to partial elevations and depressions, one portion being raised, while another is stationary or is depressed. If the conception of the globe as a fluid mass surrounded by a thin solid crust be the correct one, it is easy to see how such movements might take place; though it is difficult to point to the exact cause of any particular movement, or, indeed, of these movements in general. In some cases, perhaps, the elevating force may be steam generated by the access of water through fissures in the crust of the earth to the highly-heated interior. A more general cause, however, for these movements may be found simply in the irregular contraction of a highly-heated and heterogeneous globe, surrounded by a comparatively rigid crust, and slowly parting with its heat.

When, therefore, we meet with dry land, we believe that its existence is to be ascribed to a partial elevation of the crust of the earth at this particular point; and the chief reasons for this belief are as follows:

We find everywhere in the dry land the remains of sea-animals embedded in the rocks; this proving plainly that these rocks were originally covered by the ocean, and that, in fact, they were actually formed at the bottom of the sea. The rocks containing these marine animals occur now at various elevations above the present sea-level, having been detected as high as human observations can be made. (Fossil shells, for instance, have been found in the Himalayas at a height of over 18,000 feet.) Now, there are only two means of accounting for this fact: *either* the sea must have retired and left these rocks dry; *or*, the rocks must have been raised above the level of the sea by some agency. At first sight it would seem more likely that the sea should have altered than the solid land; but no fact is better established than that it is really the land which has changed its position.

The sea cannot sink permanently at any one point without sinking to the same amount over the entire globe. Nor, again, can the sea-level be permanently raised at one point, unless it is raised universally and equally. This single consideration is sufficient to destroy any theory that the sea either permanently retires from the land, or permanently gains upon it at any particular point simply by overflowing it.

On the other hand, passing over at present the numerous proofs afforded by geology of the movements in the earth's crust, we can actually observe the process going on in certain regions of the world. Thus, it has been established that the west coast of Greenland is gradually sinking over a space of about six hundred miles from north to south. In the same way it has been shown that a great portion of Sweden and Norway is gradually being elevated at a rate of about three feet in a century. In South America, the plains of Patagonia and the pampas of Buenos Ayres have been elevated within comparatively modern times, as shown by the existence on their surface of numerous marine shells of living species. Scotland is believed to have undergone an upheaval of about forty-five feet since the time of its occupation by the Romans. Lastly, many instances are known, in which extensive tracts of land, sometimes covering hundreds or even thousands of square miles, have been suddenly elevated or depressed contemporaneously with the occurrence of earthquakes.

We must, then, altogether give up the old belief that "the ocean was formerly universal, and that it has gradually sunk down to its actual level, so that the present continents and islands were left dry" (Lyell). On the contrary, we must believe that every portion of dry land at present above the sea-level is there in consequence of a local elevation of the crust of the earth at that point. And, not only is this the case, but geology shows us by unmistakable evidence that alternate elevation and depression of portions of the dry land has been part of the order of Nature and has been going on throughout the whole of geological time. What is now dry land has been beneath the sea, not once, but many times, and may and will be again submerged. Our present seas, in the same way, roll over what has been many times, and will again be, dry land. Thus, in the words of Sir John Herschel, "we come to perceive that the actual configuration of our continents and islands, the coast-lines of our maps, the direction and elevation of our mountain-chains, the courses of our rivers, and the soundings of our oceans, are not things primordially arranged

in the construction of our globe, but results of successive and complex actions on a former state of things; *that*, again, of similar actions on another still more remote; and so on, till the original and really permanent state is pushed altogether out of sight and beyond the reach even of imagination; while, on the other hand, a similar and, as far as we can see, interminable vista is opened out for the future, by which the habitability of our planet is secured amid the total abolition on it of the present theatres of terrestrial life."

Distribution of the Land.—As regards the distribution of the dry land, the most obvious and geologically important fact is the preponderance of the great continental masses in the northern hemisphere as compared with the southern. Thus, Europe and Asia wholly, two-thirds of Africa, and fully one-half of the American Continent, are situated north of the equator. In the southern hemisphere we find only about one-third of Africa, the greater portion of South America, and the continental island of Australia, with New Guinea, and part of Sumatra and Borneo.

Calculating the entire superficial area of the globe at about 197,000,000 of square miles, the dry land only occupies about 52,000,000 square miles, and the ocean covers the remaining 145,000,000 square miles. Of the dry land, about 39,000,000 of square miles lie in the northern hemisphere, and only about 13,000,000 in the southern hemisphere, or no more than one-fourth of the entire land-surface. On the other hand, while the ocean covers nearly three-fourths of the entire surface of the globe, more than seven-twelfths of this is found in the southern hemisphere.

The general fact indicated by the preponderance of land in the northern hemisphere is that the centre of gravity of the earth must be eccentric as regards the centre of figure of the earth; and that the eccentricity must be in the direction of the southern hemisphere, since here the greatest mass of the ocean is accumulated. This further indicates, as pointed out by Huxley, that the force which sustains our continents must be one of "tumefaction."

The relative distribution of land and water has many other important bearings, especially as concerns climate, and some of these will be noticed hereafter.

PHYSICAL GEOGRAPHY.

CHAPTER II.

Mountains.—When we come to consider the general features of the land, the first and most striking feature of all is found in the great mountain-chains which diversify the surface of the great continents. Mountains are those portions of the surface of the earth which are elevated for more than a thousand feet above the level of the sea; this limit being, of course, an entirely arbitrary one. Mountains may occur in groups, ranges, or chains, and little need be said here as to their distribution over the surface of the earth. It is curious, however, to notice the difference in this respect between the New and Old Worlds. In the New World, the great mountain-chains have a general direction approximating to a meridional one, that is to say, more or less nearly running from north to south. They not only coincide with the general axis of the continent (which, indeed, they themselves cause), but they more or less closely follow the coast-line, for a distance of over eight thousand miles. In the Old World, on the other hand, there is no single well-defined mountain-chain following the general coast-line; but there is a broad, mountainous zone, extending across Europe and Asia in a direction more or less at right angles to the meridian, or from east to west.

Kinds of Mountains.—All mountains may be looked upon as belonging to one of three kinds: mountains of circumdenudation, mountains of uptilting, mountains of ejection (Jukes).

1. *Mountains of circumdenudation* are those mountains which have been formed by a removal of surrounding matter. It is quite clear that, if the whole, or any portion of a mass of land were raised to a certain elevation above the level of the sea, and were then subjected to any forces which could remove

from the elevated portion all the external materials, we should have a group or range of mountains left standing in the centre, as a kind of backbone. Hills, then, of circumdenudation (Fig. 1) are simply masses of land left untouched out of a generally elevated region, the outer portions of which have been removed. What the forces are which produce mountains of this kind, we shall afterward see. In most mountains of circumdenudation the base of the hill is formed of the same materials or rocks as those which occur in the adjacent low ground; while the upper part of the hill is formed of rocks

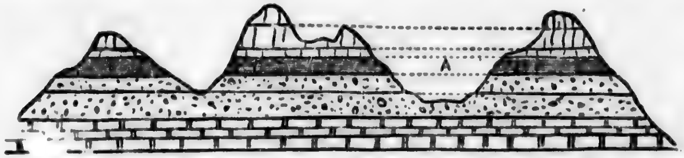


FIG. 1.—Diagram to illustrate mountains of circumdenudation. The dotted lines represent the mass of material which has been removed by denudation.

which do not occur in the low ground immediately adjacent, since they have been removed by denudation. Most of the individual hills, even in ranges of the following class, are mountains of circumdenudation. That is to say, the whole region has been elevated as a single mass, and then the mountains have been carved out of it by various "denuding" agents, which will be subsequently spoken of.

2. *Mountains of uptilting* are those mountains which have been formed by the direct elevation of a given region along a given line. As a rule (Fig. 2), the ranges formed in this way are due to the crumpling and folding up of an extensive region. Sometimes, however, the elevating forces have produced a long fissure or crack in the crust of the earth, and

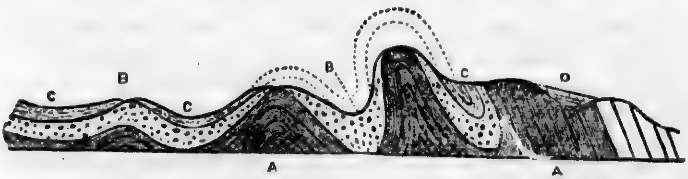


FIG. 2.—Mountains of uptilting. Section of the Appalachian chain, showing how a succession of parallel ridges has been formed by powerful folds in the rocks.

have then simply raised the portion of land on one side of the fissure, while the other side has remained stationary or sunk

down. In all cases, the mountain-ranges of this class exist, not in consequence of "denuding" forces carving them out of the general surface of the ground, but in spite of these agencies. At the same time, the individual hills of any range produced by uptilting are generally, if not universally, produced by circumdenudation. In most mountains of uptilting (Fig. 2), the central and most elevated portions of the mountain-range are found to consist of older rocks; and the low grounds consist of beds which are higher in the series, and which originally covered the entire mountain-mass, but have been subsequently removed by denudation.

3. *Mountains of ejection* are those hills formed by materials derived from the interior of the earth and raised above the surface by the action of subterranean forces through an orifice or opening in the crust of the earth. In these cases (Fig. 3), the ejected materials, of course, get piled up round the orifice through which they are expelled, so as ultimately to form a hill of a more or less accurately conical form, all the beds of which have a general inclination or "dip" *away from* the central opening. Of this nature are no other hills save only "volcanoes," and they are, therefore, of comparatively rare occurrence. They sometimes, however, attain a great size, Etna, in Sicily, being about ten thousand feet in height, and ninety miles in circumference at the base; while some of the volcanoes of the New World have a height nearly twice as great.

VOLCANOES.

Before going on to speak of valleys and of denuding agents in general, it may be as well to introduce here all that need be said on the subject of volcanoes.

What is understood by a "volcano" is an aperture in the crust of the earth from which are discharged greater or less quantities of the molten materials which form the interior of the earth, if not universally, at any rate in the locality in which the volcano occurs. Volcanoes may be either *active* or *extinct*, and they may be either *subaërial* or *submarine*. Active volcanoes are those which are now ejecting materials, or have done so in the historical period; extinct volcanoes are those which have all the characters of volcanic cones, but have not ejected materials during the historical period. In submarine volcanoes the aperture from which the molten matter is ejected —in all cases called the *crater*—is below the level of the sea; and thus the ejection of melted material is hidden from our

eyes, unless it should go on for a sufficient length of time, or for a sufficient extent, to be visible above the surface of the sea. Subaërial volcanoes are those which have the crater or aperture of ejection upon the land, and it is these with which, of course, we are best acquainted. Most of the points which should be known about volcanoes may be illustrated by Vesuvius, which has recently formed the subject of a most valuable and interesting work by Prof. Phillips, of Oxford.

FIG. 3.—Vesuvius from the west (after Phillips).

In the first place the activity of an "active" volcano is not constant, but is intermittent. That is to say, no volcano constantly emits melted matter, or even smoke or flame, except in a few exceptional cases. In the case of Vesuvius, the earliest recorded paroxysm of activity, or "eruption," took place in the year 79 A. D. Traditions existed of former eruptions, and such, no doubt, had taken place, but for many centuries the mountain had been quiescent, and exhibited to the non-geological observer no peculiarities to separate it from other mountains.

Examined in its quiescent state, Vesuvius, like any other volcano, would exhibit the following appearances: The hill would be more or less nearly conical in shape, probably considerably and often irregularly truncated at its summit. At the top, however, would be found a deep depression or pit, the remains of the old crater, the bottom of which, in the quiet

state of the mountain, would have completely solidified. To imagine a quiescent volcano, therefore, we have only to conceive of a gigantic cone, the summit of which is broken off, and which is furnished with a deep depression. This depres-

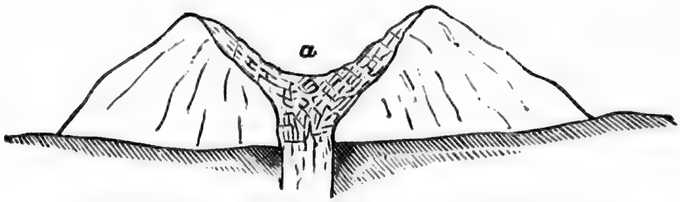


FIG. 4.—Diagram to illustrate the condition of a quiescent volcano.

sion has its floor formed by the solidified molten matter which formerly filled the vent, and its size is sometimes exceedingly great. Thus the old crater of Bromo, in Java, is between four and five miles wide, and is formed by a central floor surrounded by a ring of precipices varying from two to twelve hundred feet in height (Jukes); and these dimensions are nothing extraordinary.

When the volcano has a paroxysm of activity, far other phenomena are observable; and they are essentially the same when the volcano is a new one, or whether it has been formerly in activity. Supposing, however, the volcanic focus to have been previously active, and to have enjoyed a longer or shorter period of quiescence, the conditions of the case are these: Beneath the volcano—at no very great depth—is a vast accumulation of molten rock, which is being impelled toward the surface. We need not stop now to inquire into the nature of the forces which drive the melted matter upward, but they are almost universally admitted to be of the nature of some elastic gas, probably steam. Be this as it may, in this effort toward ejection, the impelling and elevatory forces are resisted by the weight of the volcano itself, and by the cohesion of the solidified matter which fills the ancient vent. This resistance generally gives rise to more or less violent vibrations of the ground, or earthquakes, usually attended by subterranean noises, often compared to the noise of many carts on a stony road, or to underground thunder; and not uncommonly attended with more or less elevation of the ground surrounding the volcano, this, in turn, often causing the sea to advance and retire with great rapidity, and in gigantic waves. Ultimately the contest is ended by the vic-

tory of the elevating forces; the solidified matter which chokes the old crater is blown out; or an easier solution is found in the formation of a fresh opening somewhere in the sides of the mountain.

Now the eruption proper is fairly begun, and perhaps the commonest phenomenon which indicates that the crater is open, is the presence of a vast column of vapor over the volcanic vent. This column of expanded vapors and gases is well known by the simile of Pliny, who compared it to a gigantic pine-tree, narrow below, like a great trunk, but widening out above into an enormous mass of foliage. It may remain over the mouth of the volcano for many days before any further sign is shown; and it is not at all uncommon for the clouds accumulated in this way to part with their condensed moisture, giving rise to abundant and heavy showers of rain.

The next phenomenon is generally the ejection from the crater of vast columns of what are known as volcanic ashes, scoriæ, and volcanic bombs. The "ashes" are simply the melted rock shot up by the imprisoned gases beneath to a great height in the air, and thus granulated or reduced to impalpable dust. They may be carried by the wind for great distances, even hundreds of miles; and it was by immense showers of ashes that Pompeii was buried at the great Plinian eruption of Vesuvius in the year 79 A. D. "Scoriæ," again, is the name given to portions of the melted rock or "lava," shot up above the crater in the same way as the ashes, but not reduced to powder. When thus ejected, the melted rock contains much gas or vapor enclosed in its interior, and by the expansion of these gases it is rendered cindery or spongy, with numerous irregular cells or cavities. Still larger masses of lava, thrown up in the same way, and cooling rapidly during their flight, constitute the so-called "volcanic bombs." Both the ejected scoriæ and stones are thrown up violently to a height of one to two thousand feet. If they are thrown up vertically, they simply fall back again into the crater; but if the angle of ejection be inclined to the vertical, they describe parabolic curves, and may fall at distances of from five to eight miles from the centre of eruption.

Along with the ashes, and scoriæ, and vapors of different kinds, great bursts of steam are usually emitted from the crater from time to time. The rapid evaporation of the watery vapor in these jets of steam produces a high degree of electrical tension, and consequently discharges of electricity in the form of lightning occur with great frequency and brilliancy.

The last and most familiar phenomenon of an eruption is the appearance of a true current of molten rock, constituting what is known as "lava." When the internal pressure has reached a sufficient intensity, the melted rock which fills the interior of the volcanic cone is raised ultimately to the lip of the crater; or, if the sides of the cone are weak, a fresh fissure may be made somewhere below the actual crater. In either case, the molten lava now flows down the side of the mountain, as a river of red-hot, viscous, slowly-moving fluid. Its rate of progress is not very rapid, the consistency of melted lava being something like that of thick honey or pitch. Even on slopes of thirty degrees it does not move more than a few miles an hour, and on ordinary declivities its rate of motion is not more than from a mile, or half a mile, down to thirty or forty feet in an hour. As the lava-current makes its way down the sides of the mountain, it parts, of course, with some of its heat, and, therefore, gradually solidifies. The sides and surface of the current, however, generally solidify before the centre; so that one may walk across a current that is externally converted into solid rock, but is red-hot and fluid in its centre. Very often, indeed as a rule, more than one current of lava is ejected during the course of an eruption, and generally from more than one point. In many cases, too, the current continues to flow for many days, and extends ultimately for many miles from the centre of eruption. Whenever the elevating forces have their tension relieved by the escape of the ashes, scoriæ, and lava, the phenomena of the eruption cease; and they may either return after a tolerably short interval, or the volcano may remain quiescent for many years or many centuries. Very often, however, quiescent volcanoes emit various gases and vapors, either themselves, or from minor vents ("fumaroles") in their immediate neighborhood.

These, then, are the general phenomena of an ordinary eruption of such an intermittent volcano as Vesuvius, and the subject may perhaps be rendered a little clearer by giving an account of a single eruption of this celebrated volcano. The account here chosen is the one given by Sir William Hamilton, the British ambassador at Naples, describing the great eruption of 1766, and is quoted from Prof. Phillips's work on Vesuvius:

"In September, 1765, the vapors evolved from Vesuvius grew to be considerable; in October, black smoke with clouds of steam; and at last red tints appeared in these smoky wreaths. In November, the mountain being covered with

snow, a 'hillock of sulphur' about six feet high, which had been recently thrown up, gave forth a light-blue flame from the top. . . . The eruptions, to which these smoke-ejections were prophetic or preparatory, began on Good Friday, the 28th March, 1866. A few days previously, the great and fatal image of the pine-tree appeared above the crater, and at night the smoke appeared like flame. On the day named, a violent explosion and shower of red-hot cinders occurred. At seven o'clock in the evening, the lava began to boil over the mouth of the volcano, at first in one stream," but afterward dividing into two. "The lava ran nearly a mile in an hour's time, when the two branches joined in a hollow on the side of the mountain without proceeding farther. The lava had the appearance of a river of red-hot and liquid metal, such as we see in the glass-houses—on which were large, floating cinders, half-lighted, and rolling over one another with great precipitation down the side of the mountain, forming a most beautiful and uncommon cascade. As the eruption proceeded, the lava, which at first was pale and bright, became of a deep red. In daylight it scarcely seemed fiery, but a thick, white smoke marked its course. . . . On the 10th of April, at night, the lava disappeared from the side of the mountain toward Naples, but broke out with more violence (toward Torre dell' Annunziata) on the other side. . . . Its source was a clear outburst from the side of the cone about half a mile from the mouth of the volcano. It flowed like a torrent, with violent explosions and earth-shakings. The heat was such as to forbid a nearer approach then about ten feet. The consistency of the lava was such that a stick made no impression, and stones thrown forcibly on the current did not sink in it. It ran with amazing velocity, in the first mile with a rapidity equal to that of the Severn at Bristol. The stream at its source was about ten feet wide, but soon expanded itself . . . so that at night it had the appearance of a continued sheet of fire, four miles in length, and in parts near two in breadth. . . . The vineyards and cottages were injured or destroyed, in spite of the opposition of many images of St. Januarius which were placed upon the cottages or vines. The lower part of the current was covered with red-hot stones—a kind of wall, ten or twelve feet high—which rolled on irregularly and slowly about thirty feet in an hour. The lava continued to flow at intervals, with ejections of stones and ashes, till the early part of June, or even till the 10th of December, 1766."

GEOGRAPHICAL DISTRIBUTION OF VOLCANOES.—The esti-

mated number of volcanoes which have been active within the last century and a half is about three hundred, but this number might probably be at least trebled without going beyond the facts. Little consideration can be given here to the localities in which volcanoes are found at the present day, but some of the best-known foci of volcanic action may be mentioned. In Europe are the well-known volcanic cones of Vesuvius, near Naples, and Etna in Sicily, with the cone of Stromboli in the Lipari Islands. Iceland is another ancient and equally well-known seat of volcanic energy, Hecla being the most famous of its vents. The island of Teneriffe is an enormous volcanic peak, having a height of seventeen thousand feet. On the American Continent a group of volcanoes occurs in the Chilian Andes, containing as least sixteen active vents. In Bolivia is a second group of six or eight cones occupying the elevated plateau of Titicaca. Still farther northward, on the table-land of Quito, are eighteen active volcanoes. In Central America and Mexico there is another well-known group of volcanoes. On the west coast of North America occur only two isolated cones, Mount St. Helens, at the mouth of the Columbia River, and Mount Edgecombe in Alaska. The most volcanic region of the globe is situated at the northern extremity of the Pacific, extending between America and Asia, and comprising the peninsulas of Aliaska and Kamschatka, and the Aleutian, Kurile, and Japanese islands. In this region at least fifty-one active volcanic vents are known. In the Philippines and Moluccas are other groups of volcanoes. In the Sandwich Islands are two gigantic cones (Mounts Loa and Kea), which attain a height of fourteen thousand feet. In Java are forty-six cones, varying from four thousand to nearly twelve thousand feet in height, and in Sumatra are nineteen. In New Zealand are three active volcanoes, but the volcano which in either hemisphere approaches most nearly to the Pole is Mount Erebus, discovered by Captain Ross, in the Antarctic Continent (Herschel).

From the general phenomena of the geographical distribution of volcanoes, two principal laws are deducible:

1. *When situated on islands, volcanoes are generally arranged along straight lines.* Thus, in the Aleutian Islands there are twenty-three active volcanoes, occupying a straight line of nine hundred miles in length. In the Kurile Islands, eleven active volcanoes with many extinct vents form a nearly straight line, six hundred miles in length. In Java, Sumbava, and Floris, a line of active volcanoes exists nearly eleven hun-

dred miles in length. This linear arrangement of volcanoes points to their being situated along continuous lines of fissure in the crust of the earth.

2. *When placed on continents, volcanoes are almost always in the immediate neighborhood of the sea or coast-line.* Thus, all the American volcanoes are situated on the western or Pacific seaboard, especially those of the great chain of the Andes. In fact, there are only two instances of volcanoes habitually active placed more than three hundred miles from the sea, and these two are in countries hitherto almost wholly unknown (in the Thian Shan Mountains of Central Asia). This law supports the theory that one of the main agents in the production of volcanoes is the access of the sea-water to the heated interior of the earth through fissures in the crust.

General Structure of a Volcanic Cone.—It is not difficult, on a consideration of the general course of a volcanic eruption, to understand now the ordinary structure of a volcanic cone. In the first place, we have a chasm or fissure in the crust of the earth from which great quantities of gases and steam are emitted, and hurled up with these are vast clouds of ashes, with fragments of cindery scoriæ, and larger masses of melted lava. These mostly describe parabolic curves, and fall at greater or less distances from the volcanic vent, the lightest usually falling farthest from the crater, the heaviest nearest to it. The ashes float suspended in the atmosphere, but ultimately sink to the ground, often at very great distances from their point of ejection. As this goes on, by mechanical laws a cone will be gradually accumulated round the crater; and this cone will consist of beds of ashes, scoriæ, and stones, more or less intermixed with one another, or distinct. All the beds of the cone will be found to be directed away from (or to "dip" away from) the crater, at first at a tolerably steep inclination, but gradually getting more and more nearly horizontal as we recede from the crater (Fig. 5). The crater, in

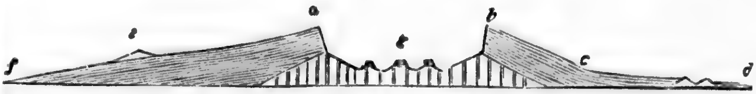


Fig. 5.—Section of the island of Palma (after Lyell).—*a b*, The old crater; *c*, Commencement of the steeper inclination of the beds; *e*, Lateral cone.

the mean while, has been kept open by the constant passage upward of steam and other vapors. The intermittent flows of melted rock or lava are found alternating with (or "inter-

stratified" with) the ashy and scoriaceous beds at different levels (Fig. 6). As, however, the flows of lava are generally irregular in strength and volume, and only last for a comparatively short time, they usually give rise to beds of irregular thickness, and mostly in the form of discontinuous masses intermixed with the ashes. From the crater, too, there proceed in all directions through the mass of the cone various fissures or cracks, more or less vertical, formed by the constant shaking to which the cone is subjected. As the fluid lava fills the crater in its endeavor to overflow, it is forced by the enormous pressure to fill all these cracks and fissures. When the lava in these fissures cools and solidifies, each fissure is converted into a *dike*, as it is called. Often these fissures extend for considerable distances, and they may all be filled with lava in this way, constituting so many "dikes," or nearly vertical walls of solidified lava, binding the whole cone into a solid mass, and perhaps extending for many miles away from the original vent.

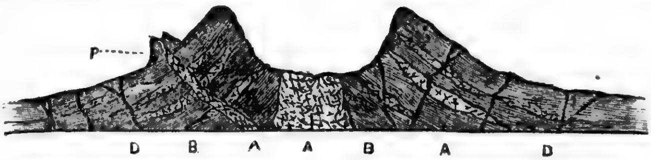


FIG. 6.—Section of a volcanic cone.—*a*, Beds of ash, dipping away from the crater; *b*, Beds of lava interstratified with the ashes; *c*, Dikes of lava cutting across all the beds of the cone. The crater is filled by a plug of solid lava.

EXCITING CAUSES OF VOLCANIC ERUPTIONS.—As regards the immediate causes of volcanic excitement, there are only two theories which need be noticed. In the first of these, it is supposed that volcanic eruptions might be caused by the presence in the interior of the earth of great reservoirs of the metallic bases of the earths and alkalies in an *unburnt* or unoxidized condition. The action of water upon such masses might no doubt produce all the phenomena of a volcanic eruption; but there is no ground for assuming their existence. The second and most generally accepted theory is, that volcanic eruptions are due to the access of water from the surface to the highly heated interior of the globe, thus causing the generation of an enormous quantity of explosive and expansive steam. This theory meets all the requirements of the case, and specially agrees with the two great facts as to the geographical distribution of volcanoes—that insular volcanoes are generally linear, as if placed along fissures, and that con-

tinental volcanoes are almost universally in the immediate neighborhood of the sea. The production of the fissures by which the sea gains access to the heated interior, as already said, is most probably to be ascribed to the irregular contraction of a slowly-cooling globe, fluid toward its centre, but surrounded by a crust of various materials and of unequal strength.

EARTHQUAKES.

Closely connected with volcanoes are those vibrations of the solid crust of the earth and those undulations in its waters which are known as earthquakes. Earthquakes consist in a series of vibrations or undulations of the crust of the earth, generally propagated from a central point or focus. The exact cause of earthquakes is more or less obscure, but it is certain that they are so far connected with volcanic action as to be always more frequent and more violent in those countries which are the present theatres of volcanic energy; while an eruption or paroxysm of volcanic activity is almost always preceded by earthquake-shocks: and the volcanic vents of a region are usually quiescent, as if relieved, during the actual continuance of an earthquake in the same district. The subject of earthquakes is so extensive that no more than a few of the leading facts concerning them can be here mentioned.

As just remarked, earthquakes occur most commonly in volcanic regions. They occur, therefore, with the greatest frequency and violence in South America, the islands of the Pacific Archipelago, Japan, Upper and Western India, Southern Europe, and parts of North America. An earthquake is generally ushered in by profound atmospheric tranquillity, and more or less disturbance in the waters of the fated region. The sea advances and retires, springs and wells dry up, or become muddy and impure; and often there are subterranean noises like the rumbling of carriages, or the thunder of artillery. The actual vibration or undulation of the ground which constitutes the *shock* rarely lasts more than a few seconds, or perhaps one or two minutes, but, if severe, this space of time will suffice for the overthrow of every elevated structure upon the surface of the affected district. Chasms and fissures open in the ground, often with the emission of smoke, flame, or torrents of water; and these fissures may close again instantaneously, or may remain permanently open; while they are sometimes sufficiently extensive to swallow up whole cities.

Very often great tracts of land, sometimes occupying many hundreds of square miles, may be suddenly uplifted or de-

pressed. When the area thus affected is part of the bed of the ocean, the result is the production of a gigantic wave, which runs out in all directions from the point of greatest elevation or depression. These "earthquake-waves," as they are called, are often of gigantic dimensions, and they are sometimes propagated for a distance of many thousand miles. Thus, in the celebrated earthquake of Lisbon, in 1755, "a portion of the coast-line sank suddenly to a depth of six hundred feet, and the result was a wave of sixty feet in height, which swept over the land, ravaged the whole coast of Portugal, and was propagated seaward quite across the Atlantic to the West Indies" (Herschel). Again, in the terrible earthquake of 1854, in Japan, a number of these colossal earthquake-waves were generated, and were propagated across the Pacific to California.

These earthquake-waves, from their mode of origin, are obviously "forced" waves, and they are commonly spoken of as "waves of translation." Various geological phenomena have been ascribed to the action of such waves sweeping across the land, but in most cases this explanation has been an erroneous one.

CHAPTER III.

DENUDATION.

HAVING now briefly considered the phenomena of mountains, we come next to consider the other features of the land, and there are none specially requiring consideration from a geological point of view except valleys. As has been shown, mountains are of various kinds, but this cannot be said to be the case with valleys. It is true that the primitive cause determining the formation of a valley is not always the same. It may be a fold or flexure in the rocks, or a crack or fissure, or a great displacement of contiguous regions, bringing into immediate contact rocks of different hardness. The cause which determines the formation of a valley may differ in different cases, but the actual work of formation is the result of the removal or "erosion" of the solid rock by means of what are known as the "denuding agents;" and this leads us to speak of the subject of "denudation."

Denudation is the general term applied by geologists to *the removal of any portion of the crust of the globe so as to lay bare an inferior or fresh surface.* Man, for instance, when he removes the soil from a rock-surface, in order to form a quarry, is a denuding agent. In the ordinary course of Nature, however, and with but a few insignificant exceptions, the denuding agents by which solid particles of matter are removed, are rain, rivers, the sea, and ice; water, in fact, in some form or other. At the same time the efficiency of these agents may be much increased, and the work of denudation hastened, by certain subsidiary agencies, which will, where necessary, be alluded to.

RAIN.—Rain is chiefly of importance as a denuding agent, from the fact of rivers owing their production to this cause, and also to the greatly increased power of rivers in heavy floods.

Rain, however, itself has a perceptible though seldom extensive action as a denuding agent. Every shower that falls exerts a certain amount of wearing and wasting influence upon the earth's surface; its effects being, of course, chiefly visible upon porous soils and incoherent materials, such as sands and clays. The action of the rain upon such materials may be studied in any ploughed field that is not absolutely level. It is unnecessary to add that the action of rain is most marked in those countries which are subject to heavy and sudden showers.

Rain also exerts a marked chemical effect upon certain rocks, especially upon limestones. This it effects by its power of dissolving carbonate of lime, a power which is much increased when it contains in solution a certain amount of carbonic acid. In this way, no limestone can be exposed for any length of time to the action of rain, without exhibiting a very marked loss of substance; and limestone may usually be recognized in the field by the worn and "weathered" appearance of its surface where exposed.

Rivers.—Rivers are most important agents in modifying the surface of the ground, and it is impossible to over-estimate the effects produced in this way by rivers acting through countless ages. The moment any portion of the earth's surface is raised above the level of the sea, so as to constitute dry land, rivers begin to be formed, and instantly commence the work of denudation, which they never cease till the whole is again reduced to the level of the sea.

All rivers owe their origin to atmospheric precipitation in the higher regions of the land. They owe their existence to the precipitation on high grounds, in the form of rain, of the watery vapor raised into the atmosphere by the heat of the sun's rays. Every little rill and rivulet, produced in this way in the higher regions of a district, tends on its way to a lower level to carry with it a portion of the solid materials which compose its bed or channel. The larger streams produced by the union of these act in the same way, and the mere existence of a *bed* or *channel* is the best proof of the existence of the action in question. The action of rivers as denuding agents, from the nature of the case, is chiefly exercised in a vertical direction, is confined to the actual channel for the time being, and is almost wholly mechanical, depending upon the wearing power of water in motion. The work done by rivers depends, therefore, upon the amount of declivity or fall in their beds, and the consequent rapidity of their currents, and also

partly upon the volume of water carried by each. This last element, however, has not so much effect as might be imagined, since the denuding power of even a small torrent may be as great as, or greater than, that of a large river, supposing its current to be proportionately more rapid. The denuding work of rivers depends, also, to a great extent, upon the nature of the rocks which form the bed; being greatly favored by the existence of soft and incoherent beds, by the presence of numerous fissures, or by the existence of great disturbance in the rocks. Thus, the Falls of Niagara owe their existence to the wearing action of the river upon a bed of soft shale which forms the base of the fall, and is capped by a hard bed of limestone (Fig. 7). The river gradually wears away and

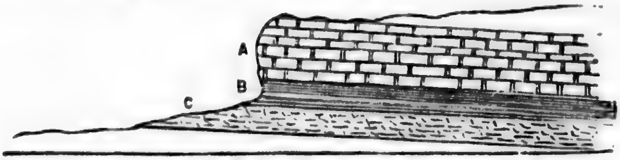


FIG. 7.—Sketch-section of the Falls of Niagara.—*a*, Niagara limestone; *b*, Niagara shales; *c*, Medina sandstones.

eats out the yielding shale, and leaves the harder limestone unsupported below. The result of this is the breaking off of great masses of the limestone left thus without support, and the fall is in this way being gradually removed farther and farther up the river. Like rain, rivers also exercise a decided chemical action upon limestones, dissolving them and wearing them away by their solvent power upon carbonate of lime.

All rivers, then, alike, in their course from the mountains in which they rise to the sea in which they end, tend to carry down portions of the land to a lower level, never wholly resting in this tendency till the materials which they carry down are delivered into the ocean.

The *amount* of matter carried down in this way varies with the nature of the rocks over which the river flows, with the rapidity of its descent from the high lands to the low lands, with the amount of water which it habitually conveys, and with its liability to sudden floods. The *proofs* of the denuding powers of rivers are partly what we see rivers doing *now*, and partly what we see they *have done* in past time.

When we see a river turbid and muddy, as in high floods, the slightest reflection assures us that this can only be from the suspension in its water of solid particles of sand or mud,

which it has gathered on its course, and is carrying down with it to a lower level. Many rivers *palpably* bring down suspended solid matter, whether they are in flood or not, and all rivers do so really, at all times, though the amount of solid matter may not be sufficient to discolor the water. To gain some idea of the amount of matter thus transported, we must look chiefly to the effects which existing rivers have accomplished in past time. These effects are twofold, and are found in the marks left by the rivers in their passage over the land, and in the accumulation of the materials which they bring down in certain localities, and especially at their point of entrance into the ocean.

Every river (Fig. 8) flows in a certain definite channel or bed, enclosed by banks of varying height, and often occupying a valley which is bounded by other banks or bluffs, also of varying height. It cannot always be asserted positively that these more distant banks are the work of the stream, though this is mostly the case, since it can often be shown

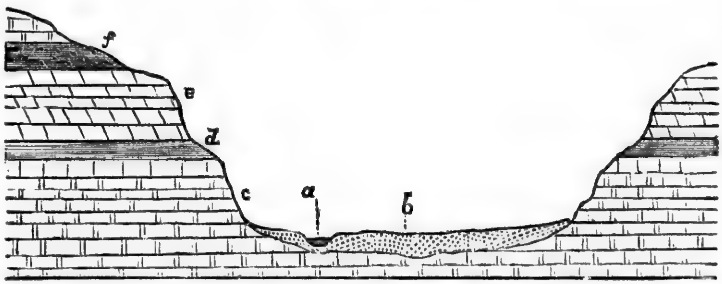


Fig. 8.—Sketch-section of the valley of the Schoharie River at Schoharie, N. Y., showing the actual bed of the river hollowed out of an alluvial plain, and bounded by precipitous, rocky bluffs.

that the rocks in these bluffs were at one time continuous, while the plain which they enclose is generally under water in high floods. In all cases, however, the actual bed of the river (Fig. 8, *a*) is the work of the river itself, and is the result of the wearing action of the river-current. Not only is this the case, but there is a constant tendency to scour out and deepen the channel by the carrying away of *detritus* to a lower level. The exact amount of work done in this way by any river varies with the set of the current in any particular portion of its course, and according to many little peculiarities of merely local origin. Thus, nothing is commoner than to find a stream

rapidly silting up and filling one portion of its bed, while it is with equal rapidity deepening its channel in another place. The wearing, or "erosive" action of a stream in forming its own channel, and in deepening it when once formed, is seen most plainly and markedly—as a matter of course—in the case of mountain-torrents. In any such, the bottom of the stream invariably shows most plainly the marks of wearing down by water, even when it passes over the hardest rocks. Often deep circular holes or caldrons—pot-holes—are formed by the whirling action of the water keeping in constant rotation a few pebbles. In all cases, water-falls scoop out deep holes, and often they undermine the ledges over which they are precipitated, and then break them off in large masses.

Another mark of the "degrading" power of water in motion is seen in almost all streams, but preëminently in mountain-streams, and that is the number of rounded stones and bowlders which they always contain. These are generally blocks of rock, which have fallen into the stream, and have become gradually rounded by the wearing action of the running water, and by friction against other blocks. By a continuance of this process, the blocks are finally converted into a number of rounded, water-worn pebbles. These, in turn, are gradually rubbed down into sand or mud, till the whole may be ground down into minute particles, and thus rendered available for transport to the ocean. The amount of solid material thus transported by rivers has been often estimated, and reaches an enormous total in the case of great rivers. Thus, the Ganges annually carries down to the sea 6,368,000,000 cubic feet of solid matter. The Mississippi brings down 3,000,000,000 cubic feet annually, and the Hoang-ho is said to bring down no less than 48,000,000 cubic feet of solid matter per day, or about 18,000,000,000 cubic feet per annum.

The work done by a river may be further estimated by the amount of solid material which it deposits at its mouth. *All* the solid matter conveyed by a river is not deposited in this way. Much is deposited at various points in the course of the river itself, and much more is carried off into the sea, or swept away by oceanic currents. Such materials, however, as are deposited, constitute an area of flat land at the mouth of the river, this being what is known as a *delta*. All rivers of any size form a delta at their entrance into the sea, and many do so where they open into a lake. In so doing, the river divides and subdivides into more or less numerous branches, and deposits the solid sediment which it holds in

suspension. In fact, the river, when its course becomes sufficiently level and its current sufficiently slow, at once begins to deposit all suspended matter; till it finally succeeds in choking up its mouth with a larger or smaller area of mud and sand, which it has itself brought down, and through which it has painfully to fight its way to the open ocean by many and tortuous channels. Most rivers form deltas of more or less size; the deltas of some are especially noteworthy for their size. The delta, for instance, which is formed by the combined efforts of the Ganges and Brahmapootra covers an area of nearly 60,000 square miles, or an area larger than that of England and Wales. In like manner, the whole, or almost the whole, of Holland has been deposited by the Rhine; Egypt, as remarked by Herodotus, is "the gift of the Nile," and the delta of the Mississippi is as large as the whole of England. We have in such deltas a measure of part, at any rate, of the denudation effected by these rivers, since every solid particle in the delta has been brought down by the river from the interior of the country. For every foot, therefore, of solid matter that is added to the delta, a foot has been removed from somewhere inland.

There are many great rivers, however, which do not form deltas, or which cannot extend them beyond certain limits. In the case of the Nile, the farther extension of the delta is prevented by a powerful marine current which sweeps its seaward edge. The Amazons, the largest river in the world, forms no delta, the volume and force of its waters being sufficient to carry out far to sea all the solid matters held in suspension, where they are tranquilly deposited at the bottom. The St. Lawrence also forms no delta, but for a different reason. Before reaching the ocean, the St. Lawrence has to pass through the chain of the great American lakes, and the greater part of its sediment is deposited in these. Other things remaining the same, the St. Lawrence will ultimately succeed in filling these lakes, and it will then begin to form a delta.

THE SEA.—Among the most powerful of the agents which tend to wear away the land and to reduce it to the sea-level, is the sea itself. The rivers, running over the land, act chiefly vertically, cutting for themselves shallower or deeper channels to form their beds. The sea, on the other hand, acts upon the margins of the land in a horizontal manner chiefly, tending gradually to cut down the land exposed to its action to a uniform level. Every portion of the land which is elevated above the sea is exposed twice in the twenty-four hours to the

abrading action of the tides all along its coasts; and the results of this are exhibited in the plainest manner along every coast-line, being, of course, more evident in those seas in which the tide rises highest, and the waves attain their greatest height and strength. The shingle and gravel-banks, and even the sand itself of the sea-shore, are almost all derived from the waste material which the sea has produced by slowly eating away the land. The pebbles in every shingle-bed on all sea-coasts are thoroughly rounded and smooth, showing that they have been gradually worn down to their present shape by being constantly rubbed against one another by every tide in its advance and recession. The finer particles produced by the further attrition of the pebbles constitute the sand and mud of the shore.

In like manner, the sea, especially during high tides, gradually undermines the land, acting most powerfully upon a horizontal plane at the foot of the cliffs which usually form the margins of the beach. The upper portions of the cliff are thus deprived of support, and slip down, forming broken masses which are easily acted upon by the waves, are gradually ground down into sand or mud, and are carried off elsewhere to form sand-banks or marine accumulations of different kinds. By this process, the land is gradually eaten away, and there are many cases in which this can be rendered palpably evident to us by authentic records, showing that centuries, or perhaps only years, ago the sea extended for many acres or even miles over what is now covered by the waves.

All the cliffs, then, which border the sea-coast have been formed by the sea itself, gradually eating back into the land. In like manner, we are forced to come to the conclusion that many cliffs and precipices now far inland have been formed at some former period by the sea, at a time when it extended much farther inland than it does now; or, to speak more correctly, at a time when the land was very much less elevated than it is at present.

If we imagine any portion of the land being slowly elevated above the sea, at the rate of a few inches or a few feet a year, it is clear that every portion of its surface will in turn form a coast-line, and will be exposed to the denuding power of the sea. We have every reason to believe that this is what really occurs. Every portion and fragment of our existing dry land has been raised from the deep, and, in the course of this process, every portion of its surface has constituted a coast-line for a longer or shorter period, according to the

rapidity with which the elevation has been accomplished. In this way, many inland cliffs, scars, precipices, valleys, and mountain-passes, have undoubtedly been formed by marine action; though in other cases we cannot suppose that the sea has been the agent employed.

By the constant repetition of these denuding actions throughout long periods, we are readily able to believe that the sea has removed from the land vast masses of rock, and has, therefore, coöperated most extensively and powerfully with the other denuding agents in producing the present configuration of the land. The action of the sea, too, does not cease altogether with its erosive influence upon the coast-lines exposed to the daily rise and fall of the tides.

There is good reason to believe that some oceanic currents have sufficient power and velocity to scoop out submarine valleys in the softer and more incoherent materials of the sea-bottom, though they can only act in shallow seas, and are not likely to affect the harder rocks.

It must be carefully borne in mind that the sea, like the rivers, *destroys* nothing of the land, but simply *rearranges* it. Every particle of solid matter which is carried off by the sea from the land is deposited somewhere else, forming part of sedimentary accumulations, which will at some future period form dry land. In many cases, by the action of oceanic currents, the materials derived from the land are conveyed to great distances, and we cannot point to their resting-place. They must, however, ultimately be deposited *somewhere*, and, in many cases, we have direct instances of this fact, in the existence of sand-banks and bars, or even in the silting up of bays and estuaries.

CHAPTER IV.

ICE AS A DENUDING AGENT.

We have now to consider an exceedingly interesting and important subject, namely, the effect of water upon the land in the form of *ice*. In ascending from the sea-level, as is known to all, there is a gradual and regular diminution of the temperature, till in every country a line may be ultimately reached, where the temperature is so greatly and permanently reduced that the snow which falls will not melt. This line is called the "line of perpetual snow," and its position varies in different countries and in different climates, being, of course, much sooner reached in cold than in hot regions. In Britain the line of perpetual snow is about five thousand feet above the sea-level; and, as there are no mountains of this height, there is no perpetual snow. In Iceland, and at the North Cape, the line of perpetual snow is about two thousand feet above the level of the sea; in Norway about four thousand feet; in the Alps about eight thousand feet; in the Equatorial Andes about sixteen thousand feet; in the Himalayas, from thirteen to twenty thousand feet; and in the Antarctic, and part of the Arctic regions, the line of perpetual snow agrees with the sea-level.

Glaciers.—It follows from the above, that all those portions of a mountain-range which lie above the level of the line of perpetual snow are constantly receiving fresh accessions of snow; and, as the snow does not melt, these annual additions would indefinitely increase the height of mountains, if it were not that a portion of the snow is constantly descending the mountains by gravitation. The pressure from behind, produced by the constant accumulation of snow above the snow-line, constantly thrusts portions of the snow down the mountain into precipitous valleys. In this process of descent from

the constantly replenished upper snow-fields, partly by pressure, and partly by thawing and freezing over again, the snow becomes gradually converted into solid ice. The result of this is that, if we take such a mountain-range as the Alps, we find the upper portion of the chain covered by a constant and permanent coating of snow; while from all the principal valleys which flank the highest hills there proceed rivers of solid ice, constituting what are called *glaciers*, and formed in the way just described (Fig. 9).

FIG. 9.—The Glacier of the Mer de Glace (from a photograph).

The general phenomena of a glacier, which are of geological importance, are these: The entire mass of ice forming the glacier is not stationary, but is constantly moving down the mountain to a lower level, exactly as a river or as any viscous fluid would do, only at a much slower rate of movement. The weight of the glacier is the cause of the movement, and its motion is rendered possible chiefly by the great facility with

which ice will break and instantly unite again by the freezing together of the freshly-fractured surfaces (a phenomenon known by the technical name of "regelation"). The rate of movement of glaciers varies from a few inches to perhaps a couple of feet in the twenty-four hours, and is different at different seasons.

As the glacier pushes itself out in the lower and consequently warmer portions of the mountain-region, its rate of advance is not sufficiently rapid to counteract the loss which it suffers by melting; so that a point is always reached at last beyond which the foot of the glacier cannot proceed. The melting which goes on at this point, as well as over the whole surface of the glacier, generally gives rise to a permanent and often very large stream, which is entirely fed by the glacier. (Thus, the source of the Ganges is from one of the great glaciers of the Himalayas, from the foot of which it issues as a muddy stream more than forty yards in width.) It is to be remembered, however, that the thickness of a glacier is so great (from two to eight hundred feet) that the ice-stream can descend far below the line of perpetual snow, before the melting is so rapid that the daily advance is neutralized. Thus the snow-line in the Alps is about eight thousand feet above the sea-level, but the glaciers descend from three to four thousand feet below this line.

Another phenomenon of glaciers of great geological importance is what is known as the "moraines." As the glacier moves slowly down its enclosing valley, innumerable masses of rock and earthy matter are detached by frost, avalanches, and other agents, and fall down upon the surface of the moving ice. In this way, the glacier becomes fringed on each side with a long line of masses of rock and soil, all along its margins, which it carries down with it to lower levels. These constitute the "lateral moraines" of a glacier (Fig. 10). If, as often happens, two glaciers coming out of separate valleys, unite into a single stream, then the *right* lateral moraine of the one and the *left* lateral moraine of the other combine to form a long line of blocks and earth which occupies the *centre* of the new ice-stream formed by the union of the two tributaries. This constitutes what is called the "median moraine" of a glacier (Fig. 10). Often there are several median moraines, and the number and position of these depend wholly upon the number and size of the tributary glaciers which coalesce to form the main ice-stream. Lastly, when the glacier reaches the point at which the rate of melting is so great as to

overcome its downward movement, all the solid materials which it carries in the form of lateral and median moraines are, of course, left by the melting of the ice, constituting what is called the "terminal moraine." The terminal moraine, then, of a glacier is a long mound, or series of mounds, of earth and stones confusedly intermixed, running at right angles to the valley, and occupying the whole front of the glacier. It is, however, seldom so perfect as this, being usually breached in various places by the stream or streams which proceed from the extremity of the glacier, and a portion of its solid materials being thus carried off into lower regions.

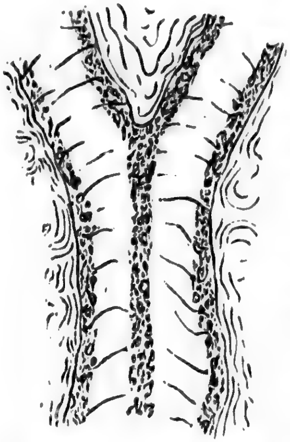


FIG. 10.—Diagram to show the lateral and median moraines of a glacier.

A terminal moraine may be easily recognized by the following points, even in places from which the glaciers have now completely disappeared: In the first place, all the materials composing any such terminal moraine would be "unstratified;" that is, they would be confusedly thrown together, the heavier blocks being mixed up with the finer earthy materials, without any arrangement into distinct beds, or, in fact, any arrangement at all. If, on the other hand, the ridge had been deposited by running water—if, for instance, it were the delta of an old torrent—this would not be the case. In this case, we should find the ridge "stratified;" composed, that is, of alternating layers of coarser or finer materials, according as the stream had power to bring down pebbles or large blocks at one time or only mud and sand at another time. *Secondly*, all the blocks in a moraine-ridge are more or less *angular*, and never completely rounded and water-worn. Having simply been carried down as they fell upon the surface of the glacier, and having mostly been subjected to no attrition or wearing down, their edges generally remain sharp and unworn, just as they were when originally broken off from the parent-rock. If the ridge had been deposited by running water, all its contained blocks would be reduced to the condition of rounded pebbles and gravel of different sizes, with water-worn bowlders. *Thirdly*, one might always detect in the blocks of a moraine

some which would be flattened upon one or more sides, the flattened side being at the same time more or less polished, and covered with more or less numerous scratches, grooves, or "striæ," usually pretty straight and similar in their direction.

These polished and striated blocks are produced in this way: As the glacier moves down the valley, it meets here and there with uneven, rocky ground, which it has to surmount. When this occurs, the glacier becomes fissured with broad and deep rents, or cracks, which are called "crevasses," and which run transversely to the axis of the glacier, generally pointing upward. Into these broad and deep fissures, rocks, sand, and earth, may be precipitated, either from the rocky banks of the glacier, or by the liquefaction of the ice surrounding parts of the moraines. The rocks thus conveyed to the bottom of the crevasse get frozen into the lower surface of the glacier, and are carried down with it in its downward course. In this course, partly by the weight of the superincumbent ice, and partly in consequence of the enormous pressure under which the glacier moves, these blocks get flattened, polished, and deeply grooved, on the face which is opposed to the rocks over which the glacier makes its way.

Reciprocally, the rocks which form the bed of the glacier are worn down, polished, and grooved, with long rectilinear furrows, by having these blocks dragged over them under such an enormous pressure. Should the stones which are fixed into the bottom of the glacier change their position from any cause, such as the melting of a portion of the ice, they will be liable to be flattened, polished, and striated upon more sides than one, and the striæ may run in different directions. In any case, however, in all the moraines of our modern glaciers, the number of striated and polished blocks is very small as compared with the total number of blocks in the moraine. On the other hand, in many ancient moraines the number of striated blocks is proportionately very large.

Let us now consider what would be the condition of a valley down which a glacier had made its way; supposing the glacier to have altogether disappeared, or to have partially retired, both cases being of common occurrence. As before said, a glacier, though moving slowly, exercises an enormous pressure, and moves with a perfectly irresistible force. As a result of this, the rocks which underlie a glacier are everywhere and in all cases more or less completely smoothed and rounded, and their salient projections worn down. Not only does this occur, but every stone and grain of sand which is

frozen into the lower surface of the glacier acts as a graving-tool, leaving its mark upon the bed of the glacier in the form of a rectilinear groove or furrow, pointing in the same direction as the course taken by the glacier itself (Fig. 11).

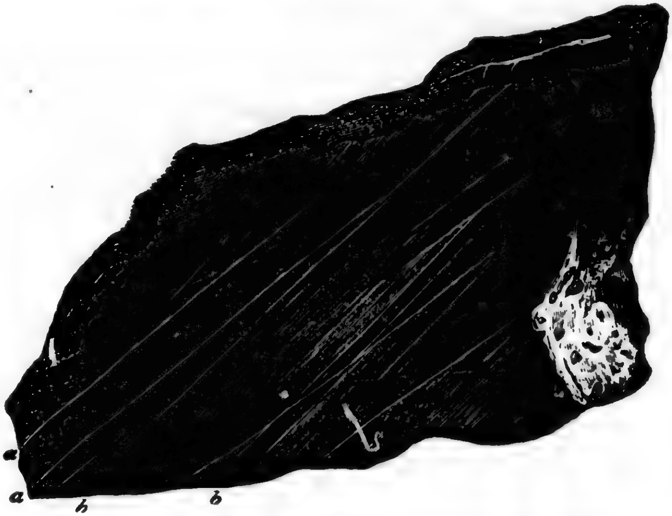


FIG. 11.—Limestone polished, furrowed, and scratched, by the glacier of Rosenlaui, in Switzerland (Agassiz).—*a a*, White streaks or scratches, formed by small grains of flint frozen into the ice; *b b*, Furrows.

Whenever, then, we find the rocks exhibiting this smoothed and rounded outline, with their surfaces polished and scored with long, straight furrows, we may be certain that a glacier has been at work. These are the phenomena which we see at the present day wherever a glacier has retired and left any portion of its bed exposed to view; and we find similar phenomena in places where there are now no glaciers. Thus, the fundamental rocks in the mountainous parts of Great Britain, and almost the whole of Europe, and over a great part of North America, are everywhere polished, smoothed, and striated. From this we know, in conjunction with many other proofs of the same fact, that all these districts, at a comparatively recent period, have been covered by great glaciers.

Another common phenomenon produced at the present day by glaciers, and found in many localities where there are now no glaciers, are what are known as "roches moutonnées" (or sheep-like rocks). These are dome-shaped masses of rock

(Fig. 12), which are flattened and rounded on the surface looking up the valley, in consequence of the passage of a glacier over them, but which generally present a more or less abrupt and rugged face on the side looking down the valley, since

FIG. 12.—Roches moutonnées, in the Lake-district of the north of England.

this side was not exposed so much to the pressure of the glacier. Equally common in glaciated countries are what are known as "perched blocks." If it should happen that any conical peak or sharp ridge should project through the glacier, and that the surface of the ice should be much lowered by melting, rings of blocks from the moraines may be left round such a peak, or a single block may be left upon such a ridge; and these are then known as "perched blocks."

What are called "erratic blocks," or simply "erratics," (Fig. 13), are of another nature, and are not so commonly pro-

FIG. 13.—The Pierre à Bot, an erratic granite block, derived from the Alps, and now situated on the Jura.

duced by glaciers as by icebergs. From the mode in which moraines are formed and transported, it follows that the blocks which are found in a terminal moraine are often quite different in composition to the rocks in the immediate neighborhood of the moraine. If we suppose, for instance, that a glacier descends a valley the upper part of which is occupied by granite,

while the lower portion is entirely composed of limestone, we should find in the terminal moraine of such a glacier numerous blocks of granite which have travelled, it might be, many miles from their source, and which now repose upon limestone, there being no granite nearer than the head of the valley. In all ordinary cases of glaciers it is quite obvious that these "erratic blocks," though they may differ from the rocks immediately adjacent, must nevertheless belong to the valley down which the glacier moves; or, in technical language, the erratics of a glacier belong to the same "hydrographical basin." In some instances, however, as in the enormous extinct glaciers which formerly occupied the Alps, this ceases to be the case. In these cases, the size of the glacier was so enormous that it was able to ignore altogether the ordinary lines of drainage; and in these cases erratics may be found many leagues from the parent-rock, and in altogether different hydrographical basins. Thus, numerous and very large erratic blocks of granite and other crystalline rocks, originally derived from Mont Blanc, are now found lodged on the limestone ridge of the Jura, at a distance of more than fifty miles from the parent rock, and after having crossed the great valley in which the Lake of Geneva is situated. In this particular case, there is good evidence that these blocks have been transported by a glacier enormously larger than any at present found among the Alps.* As a general rule, however, "erratic blocks," that is, blocks of rock which are now found far removed from their parent-rock, have been carried, not by glaciers, but by *icebergs*, as we shall shortly see. And, when transported in this way, erratics may be carried many hundreds of miles from their original source—very much farther than could be effected by any glacier.

Before passing on to consider continental ice and icebergs, one or two other common phenomena of glaciers may be mentioned. Among these are certain caldron-like excavations in the solid rock, which are called "moulins." It often happens that a stream flows over the surface of the glacier, produced by the melting of portions of the snow above. If such a stream happen to meet with one of the great fissures or crevasses which intersect every glacier, it is engulfed, and has to make its way out below the glacier. In these cases the stream forms a cascade at the point where it is swallowed up, and,

* The present glaciers of the Alps have a length of from five to twenty miles, and a thickness of from two or three hundred up to eight hundred feet. The extinct glaciers of the Alps must have been from fifty to one hundred and fifty miles in length, and from one to three thousand feet in thickness.

by the constant action of the falling stream, a deep, circular cavity or kettle is formed in the rock below. Partly by these surface-streams of a glacier, and partly by the melting of its lower end, there almost always proceeds from the extremity of every glacier a larger or smaller stream. The water of this stream is icy cold, and is charged with fine mud, derived from the glacier itself, partly from the morainic matter, and partly from the attrition of the glacier on the rocks which form its bed. By these glacier-streams large quantities of fine mud and loam are being continually carried down and deposited in the lower regions. As in the case, therefore, of rivers and of the sea, the work of destruction is constantly accompanied by an exactly equivalent amount of deposition, but the two processes, though simultaneous and equal, go on in different localities. Every particle of matter worn down by a glacier, from the rocks over which it moves, or carried down in its moraines, is preserved and accumulated somewhere else; and in many instances these "glacial" formations attain a great thickness, and are a very marked feature in the geology of a country.

Continental Ice and Icebergs.—We have now to consider the phenomena presented by glaciers and continental ice in extremely cold districts, as in the Arctic and Antarctic regions. In Switzerland the present glaciers do not descend farther than to a line about thirty-five hundred feet above the sea-level, or about four thousand feet below the line of perpetual snow. When they reach this point, they melt so rapidly that their downward progress is completely stopped. In colder countries, however, where the line of perpetual snow is much lower, we have a fresh set of phenomena. If we take such a country as Greenland, in which the snow-line is only from one to two thousand feet above the level of the sea, the cold is so great that the glaciers have not time to melt before they reach the sea-level; and they, therefore, push off now from the land into the sea. For a certain distance, they simply grate along the bottom of the sea; but ultimately the water becomes too deep to allow of this, and the end of the glacier breaks off in great masses, which float away, and are then known as "icebergs." Not only is this the case, but the cold is so intense, and the annual snow-fall so great, that, in place of any single glacier or glaciers, the entire country becomes covered with a single sheet of ice, constantly moving from the interior to the sea, and constituting what is known as "continental ice." As described by Dr. Rink, the

whole of the interior of Greenland is covered by a gigantic sheet of ice, which entirely conceals all the features of the land beneath an icy mask, and the whole of which is constantly moving toward the sea. The main outlets by which the ice is discharged are several large friths which would be the outlets of so many rivers, if the climate were milder. Down these friths the ice makes its way in colossal masses several miles wide, and hundreds of feet in thickness. These masses continue to push off into the sea, till the depth of several hundred or a thousand feet is reached, grinding along the sea-bottom as they go. Finally, when the water gets sufficiently deep to float them, enormous masses break off from the ends of these glaciers, and float away as icebergs.

It is highly probable that the condition of Scotland and Scandinavia was at one time the same as we now see in Greenland. If we could get at the land-surface in Greenland, we should doubtless see what we now observe in Scotland, namely, that all the higher regions of the country are everywhere scored and polished like the rocks which underlie a glacier.

Icebergs, then, are produced by glaciers or by continental ice, when the sea-coast is reached, and the more important phenomena which they present are these: Being detached by fracture from great glaciers, icebergs frequently carry with them enormous quantities of earth and great masses of rock, derived from the moraines. In some cases individual icebergs have been calculated to have carried from fifty thousand to one hundred thousand tons of soil and rock. When these rock-laden bergs have drifted to a latitude so low that they melt, this burden of rock and soil is, of course, deposited upon the floor of the ocean. In this way, an incalculable quantity of solid matter is annually removed from the neighborhood of the poles, and deposited at some point nearer the equator; and in this way numbers of large angular "erratic blocks" are at the present day deposited on the bed of the sea, many hundreds of miles, it may be, from their original source.

This action of bergs explains the constant occurrence of erratic blocks i arious parts of Europe and America, in regions where there are now no glaciers, and at distances from the parent-rock too great to allow us to suppose that they could have been transported by glaciers. By the putting together of a number of facts of this kind, it has been demonstrated that a large portion of Europe and America has at a recent geological period been submerged beneath the waters of an icy sea, carrying numerous icebergs laden with rock and earth.

In many cases, owing to the set of oceanic currents, or the prevalence of particular winds, the great majority of the icebergs derived from any special region may be drifted in one given direction. In this way, trains of erratic blocks and masses of unstratified matter may be produced or accumulated along particular lines.

It only remains to add, that the size of many icebergs is most enormous. Many have been carefully measured, which were from one to two hundred feet above water, and from two to five miles in length. As the specific gravity of ice is such that only one-tenth of a mass of it can appear above water, the real height of these stupendous bergs must have been from one to two thousand feet. It need not be said that the momentum of such a floating mass must be exceedingly great.

Frost.—Before leaving this subject, it may be mentioned that considerable denuding power is exercised on a small scale by frost alone. The freezing of the water which penetrates the interstices and fissures of rocks is accompanied with an irresistible expansion, by which almost all rock-masses suffer more or less waste during the course of every winter. The result of this action is to detach larger or smaller fragments bodily, and to render the whole mass more liable to the attacks of other denuding agencies.

CHAPTER V.

ACTION OF THE ATMOSPHERE AND OF LIVING BEINGS UPON THE EARTH.

WEATHERING.—The last denuding agent which requires notice is the atmosphere, with its contained gases and moisture; and the effects of this may be either chemical or mechanical. The chemical actions of the atmosphere upon rocks may all be considered under the head of "weathering." It is well known that no rock-surface can be exposed for a sufficient length of time to the action of the atmosphere without undergoing a certain amount either of actual disintegration or of chemical change. The effects produced vary with the ingredients contained in the atmosphere, and also with the nature of the rock itself. Many rocks yield much more rapidly than others, those yielding most quickly which contain any element which is soluble in carbonic acid dissolved in water. Thus, limestone may be almost invariably recognized in the field by the fact that its exposed surface is generally fretted and worn into cavities and hollows; this being due partly to the action of rain-water holding carbonic acid in solution, and partly to the atmosphere alone when sufficiently moist. Again, all rocks which contain soluble silicates, such as granitic and trappean rocks, yield more or less to the action of the air. In these cases the carbonic acid of the atmosphere, though a weak acid, replaces part of the silicic acid of the silicate, and converts it into a soluble carbonate. Hence, in almost all basalts and trap-rocks the weathered surface will effervesce upon the addition of a mineral acid. Rocks, composed of pure silica, such as sandstones, are almost indestructible by the atmosphere, if they are sufficiently coherent and compact. In all cases, however, the chief chemical effect of the atmosphere is to render the surface of rocks, where exposed, more porous,

and thus to pave the way for the more effective attacks of water in all its forms.

Mechanical Action of the Atmosphere.—Winds in some cases cause considerable modifications of the earth's surface, by transporting loose and incoherent sands from one place and accumulating them in another. Such "sub-aërial" deposits are the sand-dunes of parts of the coasts of Britain, France, and North America. They are wholly the result of the action of the wind upon the loose sand of the sea-shore, and they have the form of low mounds of sand generally arranged in irregular layers. In some cases, they gain considerably upon the land and do much damage. In all extensive deserts, also, similar hills are formed by the drifting together of the sands by the wind, and the surface is constantly undergoing modification from this cause.

Organic Agencies.—The denuding or destructive effects of living beings upon the earth's surface are comparatively so insignificant that they may be passed over altogether; but much material may be added to the earth's crust by the agency of living beings, and this subject requires a brief notice.

Accumulations of Vegetable Matter.—The incessant growth and decay of vegetables are constantly adding to the surface fresh matter in the form of vegetable soil or "humus." The thickness of this varies with the luxuriance of the vegetation in any particular locality, being greatest in tropical regions, and smallest in rainless districts. Vast accumulations of drift-wood are formed in various rivers, the upper waters of which pass through heavily-timbered regions; and vast masses of decaying vegetable matter are often accumulated in extensive swamps. In temperate zones, these last chiefly assume the form of "peat," which is mainly formed by the growth of mosses of the genus *Sphagnum.* Peat may accumulate to a great thickness, and it sometimes becomes an imperfect coal. We shall afterward see that "coal" owes its origin to the accumulation of vegetable matter in immense swamps.

Action of Animals.—As regards the action of animals, there are only three points which require notice: 1. *Shell-beds* may be formed by the growth and accumulation of such shells as oysters and mussels. Such beds attain a considerable thickness in some cases, and it can be shown that various shelly beds have been formed in a similar manner at various periods of the earth's history. 2. It has been shown that at the bottom of the deep Atlantic there is now forming a deposit of a white mud which is known as *ooze*, and which is composed

almost entirely of the minute calcareous shells of certain minute animalcules, known as *Foraminifera.* We shall afterward see that chalk has had a very similar origin, and that the shells of these same animals also enter largely into the composition of other less important rocks. 3. The structures known as "corals" are the skeletons of certain "zoophytes" allied to the sea-anemones, so common on every coast. Corals are composed of carbonate of lime, and, like the animal which produces them, they may be simple or compound; in other words, a coral may be the work of a single "polype," or it may be composed of the common skeleton secreted by a number of polypes united together, and forming a colony. The "simple" corals, though sometimes of large size, do not form accumulations of any note. The "compound" corals, however, form, under favorable conditions, enormous masses which are known as "coral-reefs," and which are a marked feature in many oceans, such as the Pacific and Indian Oceans. It will afterward be shown that many of the limestones which have been formed at various periods in the earth's history, owe their origin to the action of coral-polypes. They are either actually old coral-reefs, or they are composed of accumulations of fragments of coral, broken down into sand, and afterward compacted together by the action of water holding carbonic acid in solution.

When it is understood that compound corals, such as we have been speaking of, are produced by the combined efforts of a number of polypes, essentially the same in structure as our ordinary sea-anemones, it is readily intelligible that under favorable circumstances large masses of coral may be produced in this way. When these masses attain such a size as to be of geographical importance, they are spoken of as "coral-reefs," and the phenomena exhibited by these are of such interest as to demand some notice. The coral-producing polypes require for their existence that the average temperature of the sea shall not be less during winter than 66 degrees; and, as our seas are considerably colder than this, we have no coral-reefs. Reefs, however, abound in all the seas not far removed from the equator, being found chiefly on the east coast of Africa and the shores of Madagascar, in the Red Sea and Persian Gulf, throughout the Indian Ocean and the whole of the Pacific Archipelago, around the West-Indian Islands, and on the coast of Florida. The headquarters, however, of the reef-building corals may be said to be around the islands and continents of the Pacific Ocean, where they often form masses of coral many hundreds of miles in length. According to Darwin, coral-reefs may be divided into three principal forms, viz., Fringing-reefs, Barrier-reefs, and Atolls, distinguished by the following characters:

1. *Fringing-reefs* (Fig. 14, 1).—These are reefs, usually of a moderate size, which may either surround islands or skirt the shores of continents. These shore-reefs are not separated from the land by any very deep channel, and the sea on their outward margins is not of any great depth.

2. *Barrier-reefs* (Fig. 14, 2).—These, like the preceding, may either encircle islands or skirt continents. They are distinguished from fringing-reefs by the fact that they usually occur at much greater distances from the land, that there intervenes a channel of deep water between them and the shore, and soundings taken close to their seaward margin indicate great depths.

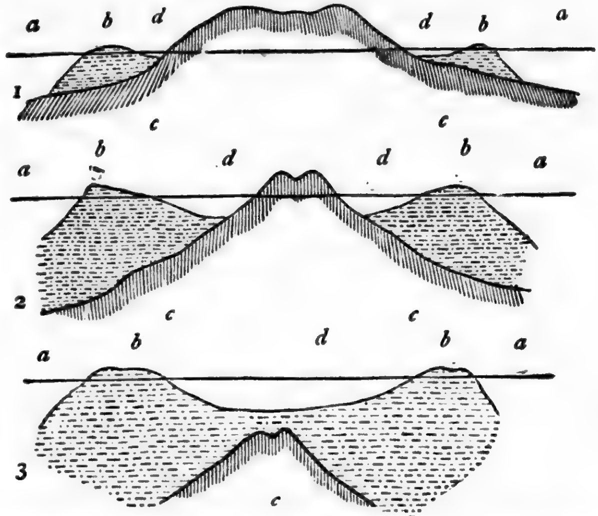


FIG. 14.—Structure of Coral-reefs.—1, Fringing-reef; 2, Barrier-reef; 3, Atoll; *a*, Sea-level; *b*, Coral-reef; *c*, Primitive land; *d*, Portion of sea within the reef, forming a channel or lagoon.

As an example of this class of reefs may be taken the great barrier-reef on the north-east coast of Australia, the structure of which is on a gigantic scale. This reef runs, with a few trifling interruptions, for a distance of more than a thousand miles, with an average breadth of thirty miles, and an area of thirty-three thousand square miles. Its average distance from the shore is between twenty and thirty miles, the depth of the inner channel is from ten to sixty fathoms, and the sea outside is "profoundly deep" (in some places over eighteen hundred feet).

3. *Atolls* (Fig. 14, 3).—These are oval or circular reefs of coral enclosing a central expanse of water or lagoon. They seldom form complete rings, the reef being usually breached by one or more openings. They agree in all particulars with those barrier-reefs which surround islands, except that there is no central island in the lagoon which they enclose.

Beyond a depth of one hundred feet below the level of the lowest tides, no portion of a coral-reef is formed of growing and living corals, but is entirely composed of dead coral or "coral-reef-rock," which is a white limestone composed of corals and shells. According to Dana, the chief kinds of coral-rock are, 1. A fine-grained, compact limestone, with hardly a trace of a coral or shell; 2. A rock equally hard and compact, but with embedded corals and shells; 3. A conglomerate of broken corals and shells; 4. A rock

composed of corals standing as they grew, the interspaces between them filled up with pounded coral, shells, and fragments.

Bearing of the Facts of Physical Geography on Geological Doctrine.—Having now considered the chief agencies which we see at work upon the globe at the present day, a few words may be said as to the bearing of these facts upon geological doctrine. There were formerly, and are still, two great schools of geological thought, the members of which are known as "Catastrophists" and "Uniformitarians." The *Catastrophists* explained all geological phenomena upon the belief that the forces which we see at present at work upon the globe formerly acted with much greater intensity than they do now, and produced, therefore, much more striking effects within the same period of time. They believed that great catastrophes and convulsions were part of the order of Nature. To explain geological phenomena, they called in the agency of intense volcanic activity, gigantic rivers rushing over the land, terrific convulsions of the crust of the earth causing elevation or depression of the land to the extent of hundreds or thousands of feet, enormous earthquake-waves ravaging whole continents, and other exaggerated physical agencies.

The *Uniformitarians*, headed by Sir Charles Lyell—the most thoughtful and philosophical of living geologists—support, on the other hand, the belief that at no period in the earth's history were the physical forces of the globe more active than we see them at present. They hold that all geological phenomena—on however gigantic a scale—can be explained by the action of the same forces which now affect the globe, working with just the same force as we see now, but acting through longer periods of time. The Uniformitarians, in fact, hold as their fundamental doctrine "the adequacy of existing causes," as it has been called. They believe that at no period of which we have geological evidence were any physical forces in existence different either in kind or in amount to those of which we have now cognizance. As a matter of course, if we assume "the adequacy of existing causes" in the production of all known geological phenomena, we must at the same time demand a vastly-extended period of geological time. A small force may produce the same effect as a great force, but it will require a much longer time proportionately to do it in.

Uniformitarianism is the basis of modern geology, and hence the importance of comprehending the leading facts of

physical geography before grappling with the problems of geology. It must be remembered, however, that, as in so many other cases of conflicting doctrines, there is some truth on both sides. In the main, doubtless, Uniformitarianism is the true key to the explanation of geological phenomena. Still, Catastrophism is not wholly false; since unquestionably there must have been times, in the earth's history, in which known forces acted with greater intensity than at present, and possibly there were even forces at work which we do not recognize now. Thus, the hypothesis that the earth is a slowly-cooling globe certainly implies that the forces of fire were at one time much more active and energetic than they are now. Whether this has been the case to any marked extent within the time of which we have geological record, is a matter for argument; but, that it has been so once, is almost certain.

PART II.

GEOLOGY.

CHAPTER VI.

Definition of Geology.—Geology, in a limited sense, is concerned with the investigation of the materials which compose the earth, and the manner in which these are arranged. Strictly speaking, this would lead us into an investigation of the earth's interior; and there are many geological phenomena which can only be explained by some theory as to the condition of the interior of the globe. Grounds, however, have already been given for the general belief that the earth consists of a cool envelope or "crust," surrounding a highly-heated interior.

Successive Formation of the Crust of the Earth.—At present we have only to do with the *crust of the earth;* that is to say, with that comparatively "small portion of the exterior of our planet which is accessible to human observation, or on which we are enabled to reason by observations made at or near the surface" (Lyell). In various ways we are enabled to form some judgment of the composition of an external shell of the earth, to the depth of, perhaps, ten miles, or $\frac{1}{400}$ of the distance from the earth's surface to its centre; and this is all that is meant by the "crust of the earth." It is quite conceivable that the whole crust of the earth might be composed of a single substance, say sandstone; but every one knows that this is not the case, and that, really, different materials occur in different places; here sandstone, there granite, here chalk, there coal, and so on. It is also conceivable that these different materials should all have been created exactly in the

same place and exactly in the same condition as we now find them. This, however, also is far from being the case. A very limited knowledge of geology shows us that the materials which now compose the crust of the earth have acquired their present position and condition slowly and under differing circumstances, and that they were *formed at successive periods*. During each of these successive periods, successive races of animals and plants inhabited the earth, and remains of these, in greater or less plenty, are preserved in the rocks of each period, constituting what are known as "fossils."

DEFINITION OF THE TERM "ROCK."—The crust of the earth, then, consists of various different materials, produced at different successive periods, occupying certain definite spaces, and not confusedly mixed together, but exhibiting, on the contrary, a definite order of arrangement. All these materials, however different in appearance, texture, or composition, are called "rocks" by the geologist. Technically, therefore, the term "rock" is to be understood as applying to *all* the materials composing the crust of the earth. In the language of geology, the finest mud, or the loosest sand or gravel, is just as much *rock*, as is the hardest and most compact granite.

CLASSIFICATION OF ROCKS.—All the rocks which compose the crust of the earth may be classed under one or other of four great divisions, known as the *Aqueous*, *Volcanic*, *Plutonic*, and *Metamorphic Rocks;* and each of these requires special consideration.

I. AQUEOUS ROCKS.—These are often spoken of as the *Sedimentary* or *Fossiliferous* rocks, and they constitute by far the greater part of the crust of the earth. They are distinguished from the other rocks by two facts: Firstly, all aqueous rocks are *stratified;* that is to say, they are composed of a number of different layers or *strata* (Fig. 15). These layers may consist of a single material, as of sandstone, limestone, or the like, or they may consist of different materials. In all cases, if we extend our examination of the aqueous rocks sufficiently far, we find that they are not only composed of successive layers, but that one set of beds or strata of one kind follows another set of beds of another kind. Beds of sandstone alternate with beds of limestone, succeeded by beds of shale, and so on. There is, therefore, a succession of the beds of aqueous rock, but the succession is not a uniform and constant one; nor are the beds of one kind referable to one period of the earth's history, and the beds of another kind to

another. On the contrary, beds of *all* the known kinds of aqueous rocks have been formed during each great geological period.

Whether composed of a single substance, or of many such alternating with one another, a stratified rock may be composed of layers of different degrees of thickness, varying from the thickness of writing-paper up to many feet. In some cases, especially in some sandstones and conglomerates, the strata are of such thickness that when a small piece alone is examined, it is impossible to make out the nature of the rock, and the stratification is only visible on a large scale. In most stratified rocks there is a double composition out of distinct layers. In the first place, the rock is divided into a series of tolerably thick layers, which separate readily from one another, since, in fact, their surfaces are not actually continuous. These layers are the true *strata*. In the second place, each *stratum* is generally composed of a greater or less number of minor layers, of different grain or color, and which do not readily separate from one another. At the same time, if force be applied to the rock, it will split more readily along the line of these layers than along any other line. These layers are usually spoken of as the *laminæ of deposition*, or simply as the *laminæ* of an aqueous rock.

As regards the origin of the stratified rocks, we are able to infer that the materials which compose them have formerly been *strewed out* by the action of water, from what we see on a smaller or larger scale wherever there is water in motion. As we have seen, every stream, where it runs into a lake or into the sea, carries with it a burden of mud, sand, or rounded pebbles, derived from the waste of the rocks which form its bed and banks. When these materials cease to be impelled by the force of the moving water, they sink to the bottom, the heaviest pebbles, of course, first, the sand and finer pebbles next, and the finest mud last. Ultimately, therefore, there is formed in every lake a series of stratified rocks, produced by the streams which flow into the lake. We might have inferred that this would be so, without actually knowing it to be the case; but, when a lake is drained, and we can examine its floor, we actually find such a succession of stratified deposits. These may vary in different parts of the lake according as one stream brought down one kind of material, and another stream contributed a different kind; but in all cases the materials will bear ample evidence that they were produced and deposited by running water. The finer beds, of clay or sand, will all be

arranged in thicker or thinner layers, or "laminæ," and will be more or less regularly "stratified." If there are beds of gravel, the pebbles of these will be rounded and smooth, as are the pebbles in any brook-course. And, in all probability, we should find in some of the beds the remains of fresh-water shells or plants, or of other organisms which inhabited the lake or its banks, at the time when these beds were in process of formation.

As we have seen, also, most large rivers deposit much of the materials which they bring down, at their mouths, forming "deltas." When such a delta is cut through, either naturally or artificially, we find that it is composed of a succession of horizontal layers of sand or mud, varying in mineral composition, in color, or in grain, according to the nature of the materials brought down by the river at different periods. In other cases, no delta is formed, but all the materials carried down by the river are hurried out to sea, to be finally deposited in alternating beds in some distant and tranquil portion of the ocean. Lastly, the sea itself is constantly preparing fresh stratified deposits by its own action, irrespective of the materials incessantly delivered over to it by rivers. As already explained, the sea upon every coast is constantly wearing back into the land, and breaking up its component rocks to form the shingle and sand which we meet with on every shore. The materials thus obtained are not lost, but are finally laid down somewhere in the form of fresh accumulations of rock.

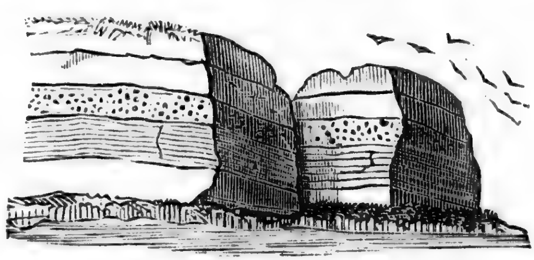


FIG. 15.—Section of stratified rocks (after Sir Henry De la Beche).

Whenever, then, we find anywhere inland any series of rocks having these characters—composed, that is, of distinct layers, the particles of which, whether large or small, show distinct traces of the wearing action of water—we are justified in assuming that they have been laid down by water at some

former period in the way described. Either they were laid down in some ancient lake, by the combined action of the rivers which flowed into it, or they were deposited at the mouth of some ancient river, forming its delta, or they were accumulated at the bottom of the ocean. In the first two cases, any remains of animals or plants which the beds might contain would be the remains of such as inhabit fresh water, or live upon the land. In the third case, any organic remains present would be in great part or entirely those of marine animals.

The fundamental and essential character of all aqueous rocks, then, is that they must be *stratified*, or arranged in distinct layers (Fig. 15). In the second place, however, the great majority of aqueous rocks show their origin quite as conclusively by the fact that they contain *fossils*. By the term "fossil" is understood "any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes" (Lyell). It is true that there are many individual beds in any stratified formation, or in some cases a whole series of beds, perhaps to the thickness of thousands of feet, in which no fossils of any kind can be detected. In these cases, however, evidence can always be obtained otherwise that these "unfossiliferous" beds were formed by aqueous agency, and they can almost always be shown to be harmoniously related to other beds which are "fossiliferous," or contain fossils. The nature and character of the fossils in any given stratum or group of strata will always afford accurate evidence as to the mode of its deposition. If the beds contain the remains of animals similar to those which now live in the ocean, we know that they were deposited at the bottom of the sea. If the fossils are those of animals and plants such as now inhabit fresh water, we know that the beds are "fluviatile" or "lacustrine;" that they were laid down in some river or in a lake.

The term "formation" is employed by geologists to designate groups of rocks which have been laid down during one period, which have a common origin, or which have some common character as regards their composition. Thus we may speak of stratified and unstratified formations, aqueous and igneous formations, fresh-water and marine formations, fossiliferous and unfossiliferous formations, secondary and tertiary formations, and so on.

The two tests, then, of any given rock having an aqueous origin, are *firstly*, that it must be stratified or disposed in distinct layers; and, *secondly*, that it may contain fossils, or, if it

does not, that it will be harmoniously related to beds that do contain fossils. There are two cases, however, in which both these requirements are fulfilled, and the rock is nevertheless not aqueous in its origin, nor in its mode of formation. In one case we may have stratified deposits formed by the ashes emitted from a volcanic vent, and simply falling on the surface of the land; and these may contain the remains of animals or plants, imbedded in them as they fell. Or, these ashes may fall into a lake or into the sea, and may become very regularly laminated; but in this case the beds become aqueous as to their actual mode of deposition, though as to their origin they are volcanic. Secondly, stratified accumulations of drift-sand may be heaped up along a sea-coast or in a sandy desert, by the action of the wind alone; and these also may sometimes preserve in their interior the remains of animals or plants. Both the cases here alluded to are rare, and both are tolerably easy of reference to their true causes.

II. Volcanic Rocks.—The second great class of rocks is that of the volcanic rocks, comprising all those rocks which we have reason to believe have been formed by the action of subterranean heat, in the same way as we now see in our volcanoes, whether these be upon the surface of the land or beneath the sea. The volcanic rocks, as a general rule, are devoid of fossils, and are mostly unstratified; but cases occur, as remarked above, in which they are more or less perfectly stratified, and contain imbedded organic remains. These, however, are exceptions and do not invalidate the general statement. Under the head of "Volcanic Rocks," are included all those rocks which form the cones of existing volcanoes, or have proceeded from them, or which are in direct connection with hills which can be shown to have been formerly volcanoes, though now exhibiting no signs of volcanic activity. Under this head, also, comes a vast series of rocks which cannot now be shown to be directly connected with any volcanic vent, though we can certainly infer from their characters that they were so connected at some former period. The rocks alluded to are spoken of as the *Trappean Rocks*, and they occupy large areas in almost every country in the world. As just said, it is impossible now to point to the original cones and craters from which these "trappean rocks" have proceeded; but their characters enable us to assert positively that they were produced essentially in the same way as we see similar rocks produced at the present day by existing volcanoes.

Thus, the trappean rocks consist of beds of solid "trap-rock," identical in mineral composition, in structure, and in all essential characters, with the lava-flows of any modern volcano; or exhibiting only such differences as can readily be explained. Associated with the beds of solid trap are other beds of "trappean ashes" exactly similar to the ashes and cinders showered forth by recent vents. We further find that the beds of trap-rock have baked and burnt the other rocks with which they have come in contact, just as a current of lava would do. Lastly, we often find that these trap-rocks cut through other formations, forming *dikes*, which alter the rocks on both sides of them; just as do the lava-dikes formed at the present day by the injection of molten matter from volcanoes into fissures in the crust of the earth (Fig. 16).

There can, therefore, be no doubt as to the substantial identity of the "trappean rocks" with the products of recent volcanoes; and it is sufficient to remark here that the absence of cones and craters in connection with the former is readily explained. In the first place, all the regions which now exhibit trap-rocks have been subjected to enormous denudation; and the surface which we now see is in no way the original surface of the ground at the time when the rocks in question were formed. Secondly, there is abundant evidence to show that most trappean rocks were formed by *sub-marine* volcanoes, and were, therefore, emitted from openings in the bed of the ocean, and not from chasms in the dry land. It is only in the case of *sub-aërial* volcanoes, as a general rule at any rate, that any cone is formed at all; and if such a cone were formed by a sub-marine volcano, it would certainly be rapidly destroyed on the cessation of the volcanic action by the denuding power of the waves of the sea.

III. Plutonic or Granitic Rocks.—The two classes of rocks which we have been previously considering are unquestionably natural groups, and we can point to two similar classes of rocks in process of formation at the present day, by agencies which we know and can observe. The remaining two classes of rocks differ altogether from any thing which we can see actually in process of formation now. For this reason they are more or less artificial divisions, and any theories as to their exact origin and mode of production are more or less open to question.

The plutonic or granitic rocks agree with the solid traps and with the modern lavas in being unstratified and in containing no fossils; while they differ from both of these in

their highly crystalline texture. It is well known that, when crystals are formed from melted matter, the size of the crystals depends mainly upon the rapidity with which the mass is allowed to cool; the largest crystals being formed when the cooling takes place most slowly. If a piece of ordinary basalt or whinstone be melted, we obtain a fused mass, all the particles of which are free to move upon one another, and are, therefore, free to assume a crystalline form, if allowed to do so. If such a melted mass be cooled with great rapidity, as by exposing a portion of it to the air, or pouring it into water, it will solidify into an actual *glass*, exhibiting no distinct crystals. If allowed to cool with moderate slowness, the rock will be more or less nearly reconverted into its original condition, that of an uncrystallized paste having exceedingly minute crystals imbedded in it. The longer, however, the process of cooling can be protracted, the larger will be the crystals; and, if we could lengthen the cooling sufficiently, the whole mass would become crystalline. These unquestionable facts supply us with the chief positive elements which we have in determining the origin of granite and the other plutonic rocks. We know that the materials which compose granite have at one time been more or less perfectly fused or semi-fused; as shown by the unstratified nature of masses of granite, by their breaking through the stratified rocks and sending veins into them, and by their baking and otherwise altering the rocks with which they come in contact. We know, moreover, that while the particles of granite must have been once free to move upon one another in consequence of partial or complete fusion, the process of cooling must have been one of extreme slowness. This is shown by the fact that granite and its allies invariably consist of numerous crystals of different substances confusedly imbedded in an uncrystallized paste or matrix. Not only so, but, in any large granitic mass, a specimen taken from near its centre, where the cooling was most protracted, will be more coarsely and largely crystallized than one taken from the circumference of the mass, where the cooling was most rapid; while a specimen taken from close to where the granite comes into contact with the neighboring rocks will have cooled so rapidly that it is quite fine-grained and hardly exhibits crystals at all, or only very small ones. Lastly, we know that the granitic rocks are rarely or never found resting upon other rocks, as if they had overflowed them; whereas the volcanic rocks are constantly found in this position. For this reason, though granites often pierce other formations, the granitic

rocks have been not unaptly termed the "underlying rocks," while the volcanic rocks are termed the "overlying rocks."

The chief positive facts, then, that we know about the granitic rocks, are these: 1. Granitic rocks underlie other formations, and, though they pierce them, they do not overflow them. 2. The materials of the granitic rocks have certainly been fused or semi-fused. Besides the proofs already mentioned, this fact is further shown by the occurrence in the crystals of granite of microscopically small cavities filled with gas or half filled with water. This last fact shows that, though granite has been fused, the temperature at the time of fusion could not have been very high, or else the fusion took place under enormous pressure; for it shows that the melted granite must have been permeated by steam. 3. Granitic rocks must have cooled with exceeding slowness, as their component crystals are often of very large size.

From these and similar facts the following general conclusions appear to be deducible:

Firstly. All granitic rocks have not had a similar origin, but there are probably two classes of granites, of which one has been formed mainly by igneous action, while the other has been produced by an alteration of previously-existing rocks, so that it would more properly come under the head of metamorphic rocks.

Secondly. The granitic rocks of either class have been formed by the agency of heat acting under great pressure, and probably in conjunction with watery vapor or steam. The granitic rocks, therefore, have their origin at great depth below the surface of the earth; hence their character of being "underlying rocks."

IV. METAMORPHIC ROCKS.—The metamorphic, or stratified crystalline rocks, or crystalline schists, as they are sometimes called, include a number of rocks, of which the best known are gneiss, mica-schist, roofing-slate, and statuary marble. All these show certain points of affinity to the granitic rocks; and there are strong reasons for believing many of the granitic rocks owe their origin to a further continuance of the same process as that by which the metamorphic rocks are produced.

The metamorphic rocks agree with the granitic rocks in possessing a more or less completely developed crystalline texture. This is shown most markedly in such metamorphic rocks as gneiss and mica-schist, less so in statuary marble, and not at all, or only in a modified form, in roofing-slate,

which last, indeed, can only occasionally be properly classed with this group. On the other hand, the metamorphic rocks differ from the granitic rocks in always exhibiting a more or less distinctly stratified arrangement. This is not so much seen in the capability of being split into separate laminæ, a capability which may be present or may not, and which may or may not be coincident with the original stratification; but it is seen rather in the fact that they are divided into beds which correspond in form and arrangement to the different beds of the ordinary sedimentary formations. Thus, gneiss, quartzites, mica-schist, roofing-slate, and statuary marble, may and do alternate with one another in regular beds, just as sandstones, clays, and limestones, succeed one another in the unaltered aqueous rocks. There is every reason, therefore, in speaking of the metamorphic rocks as *stratified* rocks. The metamorphic rocks, however, differ from the ordinary aqueous rocks, not only in their crystalline texture, but also in containing few or no fossils, and in rarely splitting along the original layers or laminæ of deposition. Further, it very generally happens that the action which forms metamorphic rocks develops in the rock new minerals which are not to be found in the original rocks of which metamorphic strata are merely an altered form.

This leads us to speak of the origin of the metamorphic rocks. As implied by the name "metamorphic" (Gr. *meta*, indicating change; *morphe*, form), it is believed that this group of rocks owes its origin to the alteration and *metamorphosis* of ordinary aqueous rocks. Metamorphic rocks are not produced as such in the first place, but they become so at some period subsequent to their original deposition. It is believed, namely, that metamorphic rocks are produced by the long-continued action of subterranean heat, probably in conjunction with moisture, upon ordinary stratified formations, at some period posterior to their deposition. In all probability this metamorphic action has taken place at great depths beneath the surface of the earth and under an enormous pressure of superincumbent rock; and its result has been to give a totally new texture, often with a different structure and sometimes with a different mineral composition, to the strata thus affected.

It follows from this theory of their origin, that metamorphic rocks need not necessarily be of any particular age. *Any* rock of *any* age may be converted into a metamorphic rock, if only subjected to the necessary conditions; and, as a matter of fact, it is now known that metamorphic rocks occur which

are referable to all the great geological periods. In the same way and for the same reason, it is known now that granites are of all ages. It was formerly believed that the granitic rocks had been formed at the earliest period of the earth's history, that they were anterior to the formation of all the sedimentary rocks, and that no granites had been produced after the deposition of the aqueous rocks had once commenced. On the contrary, we now know that granitic rocks have been formed in all the great epochs of the earth's history; and this renders still more probable the view that most granitic rocks are only a further stage of the metamorphic rocks, and that both owe their origin to the same agency.

The only action which we see at the present day at all comparable to what we believe has occurred in the metamorphic rocks, is the group of phenomena which we can observe where masses of melted rock have come into contact with other rocks belonging to the stratified or aqueous series. In this case, we find the igneous and once molten mass surrounded by a broader or narrower zone of altered rock, *metamorphosed* by the heat of its intrusive neighbor. Thus, chalk or limestone near its junction with a mass of trap may be converted into hard white statuary marble, slate may be changed into mica-schist, and sandstones may become quartzites. There is reason to suppose that the metamorphic rocks have been produced in a manner analogous to this; but in their case it is certain that the action must have been produced by some cause very much more general in its operation, and probably at great depths below the surface, since whole mountain-masses have been affected in this way over areas of many hundreds of square miles.

It is quite clear that the granitic and metamorphic rocks have much in common; and it is often convenient to speak of the two by some common name. Formerly it was supposed that all the granitic and metamorphic rocks had been first produced, and that then the aqueous and volcanic rocks had been formed; and upon this view the name of "Primitive Rocks" was applied to the two former classes. Now, we know that all the four classes of rocks have been produced in successive portions and at successive periods. They have all been produced contemporaneously, and may even now be in process of formation on a large scale. The name of "Primitive Rocks" must therefore be abandoned; and the best substitute is the term "Hypogene Rocks," or *nether-formed* rocks (Gr. *hupo*, below; *gennao*, I produce). This term was sug-

gested by Sir Charles Lyell upon the certainty that none of the granitic and metamorphic rocks had assumed their present form and structure at the surface of the earth. They are not by any means necessarily the lowest rocks, or the oldest in point of time; but, *in any given area* in which they occur, they are always, without exception, *below all the rocks with which they come in contact.* They are always "underlying rocks." They never repose upon any of the volcanic or unaltered fossiliferous rocks; and are, therefore, always *under* all the other rocks *of any particular region* in which they occur. For these reasons, the name of "Hypogene Rocks" may sometimes be advantageously employed as a common term to designate the metamorphic and granitic rocks.

CHAPTER VII.

AQUEOUS ROCKS.

It is now necessary to speak of each of the four great classes of rocks in greater detail, commencing with the aqueous rocks. The aqueous or sedimentary rocks may be primarily divided into the two great groups of the mechanically-formed rocks, and the chemically-formed rocks, the latter including all those rocks which owe their origin to the action of living beings.

I. Mechanically-formed Rocks.—These are all those aqueous rocks of which we can attain proof that their particles have been mechanically transported to their present situation. Thus, if we take a piece of "conglomerate" or pudding-stone, we find it to be composed of a number of rounded pebbles imbedded in a fine paste or matrix. These pebbles have been manifestly subjected to much mechanical attrition or rubbing down, and they must have been carried a long way, and much tossed about, before they were finally deposited where we now see them. In the case of a sandstone the component grains of sand are equally the result of mechanical attrition, and have been equally transported from a distance. In the conglomerate we can often point to the exact place from which the pebbles have been brought; in the sandstone we can rarely say whence the individual grains have been derived, but their mechanical origin is still obvious. In the case of still finer rocks, such as shale, the particles of the rock have been so far worn down that their source is quite irrecognizable; but a microscopical examination would still show us that the component grains were all rounded and water-worn.

Mechanically-formed rocks, then, are such as can be proved to have been *derived from the wear and tear of other pre-*

existent rocks; hence they are often spoken of as *Derivative* rocks. Every bed, therefore, of every mechanically-formed rock is an exact equivalent for a corresponding amount of destruction of some older rock. Mechanically-formed rocks may be divided into the two groups of the Arenaceous and the Argillaceous Rocks.

a. The *Arenaceous* (Lat. *arena*, sand) or *Siliceous rocks* are those which are mainly or entirely composed of larger or smaller particles or grains of flint or *silex.* The chief varieties of this group are sands and sandstones, grits, and conglomerates. *Sands* and *sandstones* vary almost indefinitely in coherence, colors, and grain, but they all consist of grains of flint or silica, of different sizes. The hardest sandstone, when first deposited, was as incoherent as the sand of the sea-shore. The conversion of sand into sandstone may be effected by pressure alone; more usually, however, the grains of sandstone are made to cohere by the percolation, through the whole mass, of water holding in solution some substance capable of acting as a cement, such as some soluble silicate, carbonate of lime, or, very commonly, an oxide of iron. If the cementing substance be some salt of iron, the sandstone will be colored with various shades of yellow, red, or brown, or, in rare cases, green. If the cementing material be carbonate of lime, the sandstone becomes more or less "calcareous;" and, if there be much lime present, a rock is produced, which might, indifferently, be called an arenaceous limestone or a calcareous sandstone.

The distinction between an ordinary sandstone and *grit,* as it is termed, is one that is very difficult to define, though every geologist knows the difference in the field. As a general definition, it may be said that the term *grit* or *gritstone* should only be applied to the harder sandstones, which consist almost entirely of grains of silica cemented together by the most purely siliceous cement (Jukes). Often the particles of a grit are imperfectly rounded or angular, but this is not essential; and, in the rock known as "millstone grit," we get a sandstone which might fairly be regarded as a very fine-grained conglomerate. No sandstones, however, or very few, are purely siliceous; but they mostly contain small quantities of some foreign substance. If lime be present, the sandstone is *calcareous;* if there are little flakes of mica in it, it becomes *micaceous;* and, if there be aluminous matter, we have an *argillaceous* sandstone.

A purely siliceous rock may be recognized by the fact that

no effervescence would be caused by the addition of a drop of any mineral acid, and the rock could not be scratched with a knife.

When an arenaceous rock consists of a number of fragments large enough to be called pebbles, imbedded in a sandy base or matrix, it ceases to be a sandstone. If the included fragments are all rounded and *water-worn*, the rock is now a *conglomerate* or pudding-stone. If the fragments are more or less angular, it becomes what is called a *breccia*. *Gravel* or shingle, again, may be said to be nothing more than a conglomerate in an unconsolidated condition. It is convenient, for many reasons, to consider conglomerates and breccias under the head of arenaceous rocks, but this is to a great extent arbitrary. Many conglomerates and breccias certainly have a sandy matrix, and are, therefore, arenaceous rocks; but many are *calcareous*, their matrix being composed of carbonate of lime. Many breccias, again, are of volcanic origin, and, though they are certainly mechanically-formed rocks, they are not aqueous.

It seems hardly necessary to point out that, in all conglomerates without exception, the included pebbles are foreign to the rock itself, and have always been derived from some older rock. In all conglomerates, therefore, the pebbles are older than the matrix. The same holds good of all breccias, except in the rare instances in which a rock has been locally broken into fragments, and has been recemented in place by the percolation of water holding some cementing substance in solution. It follows from this that when fossils occur—as they sometimes do—in any conglomerate or breccia, we have to ascertain in what part of the mass they occur, before pronouncing as to their age. If they occur in the pebbles, then they belong to the older period in which the rocks were formed from which the pebbles were derived. If, on the other hand, they occur in the matrix, then they belong to the period in which the conglomerate was formed. Thus, a conglomerate of the age of the Old Red sandstone might contain Old Red fossils in its matrix; but, if it contained any fossils in its pebbles, these would necessarily be the fossils of the older Silurian period, or of some still more remote age.

Conglomerates, like sandstones, vary extremely in hardness, as well as in the size of the included pebbles. Sometimes the pebbles may be detached from the matrix with the slightest blow; at other times the union of the matrix and pebbles is so strong, that a fracture will cut through the pebbles as well as the matrix, leaving a perfectly clean face.

b. Argillaceous Rocks (Lat. *argilla*, clay).—The second group of the derivative aqueous rocks is that of the *argillaceous* rocks, or those which contain a certain proportion of *clay.* Perfectly pure clay is a hydrated silicate of alumina, but it can hardly be said to occur in nature. The nearest approach to a pure clay is the "kaolin," or porcelain-clay, used in the manufacture of porcelain. This is derived from the decomposition of granitic rocks, but always contains some impurity in the form of siliceous matter. In ordinary language, any earth which can be kneaded with water into a plastic mass, is a "clay," but all such contain more or less sand. The ordinary argillaceous rocks or clays, in fact, contain only about one-fourth part by weight of alumina, the remainder being chiefly silica or sandy matter, mixed with variable quantities of the oxides of iron and other impurities.

The chief tests in the field for argillaceous rocks are that they give out an earthy odor when breathed upon; that they are readily scratched with a knife, or even with the finger-nail; and that they do not effervesce with the mineral acids, or only to a limited extent and under certain circumstances.

Argillaceous rocks, as a general rule, are nothing more in their origin than fine mud derived from the wearing down and decomposition of rocks containing silicate of alumina; and the following are their chief varieties:

1. *Ordinary clay*, composed of a mixture of sand and clay, colored by iron or other impurities.

2. *Pipe-clay*, containing less sand than the preceding, white, and nearly or quite free from the oxides of iron.

3. *Loam.* A friable mixture of sand and clay, in which the former so much predominates, that the whole ceases to be capable of being kneaded into a plastic mass.

4. *Marl.* Clay with variable proportions of lime mixed with it, and generally breaking up, when dry, into small cubical fragments. The term "marl," however, is very loosely employed, and is often applied to clays which contain no calcareous matter.

5. *Marl-slate* occupies the same position to marl, that shale does to clay. It is only hardened and finely-laminated marl.

6. *Shale.* This is regularly *laminated* clay, more or less indurated or hardened, and capable of being split into thin layers along the original laminæ of deposition. When it contains bitumen or other oily matter, it becomes "bitumi-

nous shale," and, when it has particles of coaly matter disseminated through it, it is said to be "carbonaceous."

7. *Clay-slate or Roofing-slate.*—This is a shale which has been so far altered that it will no longer split along the original lines of lamination, but splits along a series of planes usually not coinciding with the original stratification. It is what is called "cleaved," and is, in a wide sense, a "metamorphic" rock.

8. *Flagstone or Flag.*—This is a loose term applied to any rock which will split into thick slabs or flags. Arenaceous rocks are often flaggy, as well as argillaceous rocks.

II. CHEMICALLY-FORMED ROCKS.—The second great section of aqueous rocks comprises those which have been formed by chemical agencies. As many of these chemical agencies, however, can only act through the medium of living beings, whether animals or plants, we include under this head a number of what may be called "organically-formed" rocks.

1. CALCAREOUS ROCKS.—The most important group of these chemically and organically formed rocks comprises the so-called Calcareous Rocks (Lat. *calx*, lime); so called because they are made up of carbonate of lime, or contain a large proportion of this substance. All rocks which are composed almost exclusively of carbonate of lime are called limestone or chalk, the former being hard and compact, the latter soft and powdery.

Chalk is nearly pure carbonate of lime, and has mainly a soft texture. It is to a great extent an organically-formed rock, consisting almost entirely of the minute calcareous shells of certain simple forms of animal life, which have been already spoken of as *Foraminifera.* These make up the mass of the rock, and are invisible to the unassisted eye; but along with these are the remains of sea-urchins, shell-fish, corals, sponges, and other marine animals.

When the calcareous rock, instead of being soft and earthy, is hard and compact, it constitutes *limestone*, of which there are many varieties, formed in different ways. Some limestones are formed almost wholly of organic remains, such as corals, shells, stone-lilies, and other fossils, when the rock is truly organic. When these have grown on the spot, as we find them now, the rock may truly be said to be an old coral-reef. In many cases, however, the rock is secondarily mechanically formed; since it is composed of fragments of shell, coral, etc., mechanically transported to their present site, and then cemented together by the percolation of water holding carbonic

acid in solution. Examples of both these kinds of limestone are to be found in process of formation at the present day among the coral-islands of the Pacific.

Other limestones are fresh-water in their origin, and are formed in lakes into which run streams containing carbonate of lime in solution. Water containing carbonic acid in it—as rain and all streams do—is capable of taking up a certain amount of carbonate of lime and retaining it in solution. When, however, the water evaporates, and the carbonic-acid gas escapes, the lime, which was previously held in solution, is redeposited in a solid form. In this way are formed those pendent masses of lime which hang from the roofs of limestone caverns, and are known as "stalactites." Every drop of rain-water, namely, which percolates through the roof, takes up a portion of lime, which it is forced to part with again, as it hangs suspended from the roof, and has time to evaporate. If it succeeds in falling, it evaporates on the floor of the cave, and forms there other masses of lime, which are known as "stalagmites." In this way, also, are produced the well-known phenomena of "petrifying" springs, some of which give rise to the formation of extensive calcareous deposits. As these burst forth from the interior of the earth, they hold much carbonate of lime in solution; but they deposit this in a solid form, as they evaporate and give forth their carbonic acid. If the resulting rock is soft and spongy, it is known as "calcareous tufa;" if hard and compact, it is called "Travertine." This last owes its name to its occurrence upon the banks of the river Tiber, where it forms precipices several hundreds of feet in height, and is largely used as a building-stone.

The sea, of course, like fresh waters, contains carbonate of lime, but there is no reason to suppose that limestones are ever formed by the direct precipitation of carbonate of lime from sea-water, as does occur in some fresh waters. In the case of marine limestones, it is probable that the lime is invariably in the first place abstracted from sea-water by the agency of marine animals.

The term "marble" is applied to any limestone hard enough to take a polish. Many marbles owe their beauty to impregnation with mineral substances, or to the presence of fossils; and these do not differ essentially from ordinary limestones. Other marbles, such as "statuary marble," are crystalline, like loaf-sugar, and hence they are sometimes called "Saccharoid" limestones (Lat. *saccharum*, sugar). These are, properly, *metamorphic* rocks, and are devoid of fossils.

When the limestone is composed of small, rounded grains, like the roe of a fish, it is said to be "oolitic," or to be an "oolite." This structure is generally due to the deposition of concentric layers of carbonate of lime round separate grains of sand, which act as independent nuclei for this action. When the grains are of large size, like peas, the limestone is said to be "pisolitic" (Lat. *pisum*, a pea).

When limestones contain much siliceous or flinty matter, they are said to be "cherty" or "siliceous" limestones; but very often the "chert" is only disseminated in scattered masses in the limestone, and the whole rock is not siliceous.

If much aluminous matter is present, the rock becomes an "argillaceous" limestone; and if alumina and silica are present in such proportions that the rock forms a mortar, which will consolidate or "set" under water, then the limestone is said to be "hydraulic."

The most important variety of limestone is dolomite or *magnesian limestone*, which owes its characters to the presence of a certain amount of carbonate of magnesia intermixed with the ordinary carbonate of lime. The presence of magnesia is indicated by a peculiar sandy feel, and gritty texture, accompanied, in the more genuine dolomites, by a characteristic, pearly lustre. Further, magnesian limestone does not effervesce with acids as readily and violently as ordinary limestone; while its color is generally, though by no means invariably, some shade of yellow or brown. Magnesian limestone varies much in character, being sometimes soft and earthy, sometimes hard and compact, sometimes splitting into thin layers, and sometimes looking as if composed of a number of rounded "concretions," which may be as small as grapes, or as large as cannon-balls. In its origin, also, it varies. Sometimes the rock contained magnesia at the time of its deposition, and was, therefore, a magnesian limestone from the beginning. In other cases there is direct proof that the rock, when first deposited, was an ordinary limestone not containing magnesia, and that this substance was introduced into the rock at some later period. How the original limestone became "dolomitized," as it is often called, is not altogether certain.

In the field, limestone may usually be recognized by its peculiar mode of weathering, owing to the solvent action of water upon it, its surface being generally more or less worn into irregular hollows and cavities. It may also be known by the appearance and texture of its fractured surface, and by its being generally divided into pretty regular and even blocks

by regular lines of division or "joints." In any doubtful case, however, the addition of any strong acid, as nitric or muriatic acid, will decide the point. If carbonate of lime be present, there will be effervescence from the liberation of free carbonic-acid gas; and the more calcareous the rock may be, the more rapid and violent will be the effervescence. Chalk, as being nearly pure carbonate of lime, effervesces most violently, and may be nearly altogether dissolved; but magnesian limestone effervesces only slowly and feebly.

2. Gypsum.—Gypsum is a hydrated sulphate of lime; that is to say, it is composed of sulphuric acid in combination with lime and two atoms of water. It occurs as a rock in various forms, but it is not found very commonly in large masses. Generally it appears as a soft, yellowish-white or white rock, somewhat of the texture of loaf-sugar, but often more coarsely crystallized, or fibrous. It generally occurs in pretty regular beds, sometimes of considerable thickness; but it is often found in irregular masses or cakes, or in the form of veins and strings disseminated through other rocks. Not uncommonly, marls and clays are impregnated with gypsum, and are then said to be "gypseous." *Alabaster* is a granular and compact variety of gypsum, which is used in sculpture, but is not of common occurrence. Gypsum may be distinguished in the field from all forms of carbonate of lime by remaining unaffected by the mineral acids.

Rock-salt.—This, like gypsum, is by no means generally distributed. It mostly occurs in the form of irregular cakes, which may be fifty or sixty feet thick in the middle, but which rapidly diminish in thickness, or "thin out," in every direction, as the circumference of the mass is approached. The salt may be quite pure, or may be more or less contaminated by various earthy impurities. In a great many cases, beds of rock-salt are found to be associated with red, green, or variegated marls, or with masses of gypsum; but the origin of rock-salt will be alluded to in speaking of the New Red Sandstone.

Coal.—This is the last of the organically-formed rocks which requires mention, but its origin and leading characters will be treated of at length in speaking of the Carboniferous Rocks. Whether in the form of ordinary bituminous coal, anthracite, or lignite, coal is formed out of vegetable matter. In all cases, therefore, coal approximates more or less closely in chemical composition to wood. It consists, namely, of from seventy to eighty per cent. of pure carbon, with varying quan-

tities of oxygen and hydrogen, and a small quantity of earthy or mineral matter, this last constituting the *ash* of coal when burnt. All coals occur in the form of beds in other stratified rocks, and there are innumerable gradations from pure coal, into earthy coal, and carbonaceous shale, till ultimately ordinary shale is reached. It follows from this that coal is not a *mineral*, with a definite form and a definite chemical composition, but it is a *rock*, and as such is liable to an extensive series of variations in composition without losing its title to be called coal.

GRADATIONS BETWEEN THE GROUPS OF AQUEOUS ROCKS.—The division of the Aqueous Rocks into the three great groups of the Arenaceous, the Argillaceous, and the Calcareous Rocks, is a very convenient one in practice. It is to be borne in mind, however, that in Nature no hard and fast line can be drawn between the great groups of Aqueous Rocks; but that they may, and commonly do, pass into one another by a number of insensible gradations. Thus, purely siliceous sandstones are exceptional, but more or less argillaceous or calcareous matter is usually present, till ultimately we get an argillaceous or calcareous sandstone. Few limestones are without some admixture of aluminous matter or clay; and the impurity may be so marked a feature that we are compelled to call the rock an argillaceous limestone. Or, again, a limestone may have so much sand mixed with it as to become "siliceous." In the same way, shales may be so impregnated with quartzose matter, that they become "sandy shales," or "shaly sandstones," just as we may choose to call them. Or, there may be so much lime present, that the rock will effervesce with acids, and becomes a "calcareous shale."

Again, no rigid line can be drawn between the chemically- and the mechanically-formed rocks in practice. Most limestones are primarily of the nature of chemically- or organically-formed rocks, but they are often secondarily mechanically-formed rocks; or, at any rate, they have undergone such changes since their deposition that their exact origin cannot be determined.

CHAPTER VIII.

VOLCANIC ROCKS.

UNDER the head of "Volcanic Rocks" are included not only the rocks produced by modern volcanoes, but also those which we have reason to suppose have been formed by volcanoes now no longer in existence. The general mode of the occurrence of the Volcanic Rocks is threefold. They occur, in the first place, in the form of solid masses surmounting or penetrating other formations, generally of no very great horizontal extent, but showing evident marks that they have, at some former period, been melted or fused. In the case of modern volcanoes these masses constitute the "lavas," but in the case of the older rocks, where no cone of eruption is now to be found, they constitute beds of different kinds of "trap." In either case they are devoid of stratification, and destitute of fossils. They mostly form tabular masses, the edges of which constitute abrupt escarpments, or cliffs; and it is from this peculiarity that the older examples are known as "traps," from the Swedish word "trappa," a flight of stairs, trap-hills generally exhibiting a stair-like terraced appearance.

Secondly, the fused materials, though precisely the same as the preceding, instead of forming tabular masses or nearly horizontal sheets, have been forced into fissures which have a more or less nearly vertical direction. They then intersect other formations as wall-like masses, and they are known as "dikes" (Fig. 16).

Thirdly, in addition to these two kinds of originally melted rock, we have another group of volcanic and trappean rocks, which is purely mechanical in its origin. The rocks of this group are produced by the showering forth from the volcanic vent of clouds of impalpable ashes with larger or smaller fragments of stone; the whole derived from the melted lava filling

the crater, by its forcible disintegration and dispersal in consequence of the explosive escape through it of expansive gases. The materials produced in this way are often ejected in enormous quantities, and they mostly fall in the immediate

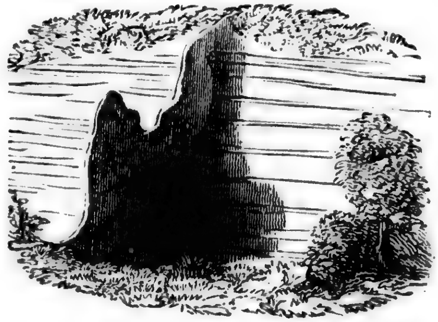


FIG. 16.—Dike in a valley near Brazen Head, Madeira. (From a drawing by Captain Basil Hall, R. N.)

neighborhood of the volcanic orifice, constituting a series of beds of greater or less thickness. If the volcano is submarine or near the sea, the ashes and scoriæ thus emitted usually become regularly stratified, and they *may* contain fossils. If they fall on land, they will exhibit a rough and irregular stratification, but not nearly in so perfect a manner as if they had been arranged and assorted by water. As produced by existing or extinct volcanoes, these mechanical accompaniments of an eruption are spoken of as volcanic ashes, tuffs, and scoriæ. As produced by the ancient and no longer visible volcanoes from which the traps proceeded, they are spoken of as felspathic ashes, trappean ashes, trap-tuffs, and trappean breccias. In both cases their nature is essentially the same.

As the mechanically-formed ashes, tuffs, and breccias, are produced by the forcible breaking up and disintegration of the melted lavas and traps, it follows that the two sets of rocks are identical in chemical composition; since they are, in fact, nothing more than different physical states of the same rock. In making, therefore, the brief remarks which follow, on the mineral composition of the volcanic and trappean rocks, no distinction need be drawn between these groups.

All volcanic and trappean rocks may be looked upon as essentially composed of two great families of minerals, *felspar* and *hornblende*, each of these names being used in a general

sense to cover a great variety of different species of minerals. All the volcanic and trappean rocks are produced by the intermixture of different members of the felspathic and hornblendic groups of minerals in different proportions. An enormous variety of rocks is thus produced, most of them known by special names, and only to be accurately determined by an elaborate chemical analysis. For our present purpose, however, it will be quite sufficient to understand the general composition of the felspathic and hornblendic groups of minerals, and the characters of the more important rocks which are formed by their intermixture.

All the *felspars* may be regarded as essentially silicates of alumina, combined with the silicate of some alkali, such as potash, soda, or lime; so that they may be looked upon as a kind of *glass*. The leading varieties of felspar are distinguished by the predominant alkali which they contain, as potash-felspar, soda-felspar, etc.

The chief varieties of felspar are:

1. *Orthoclase*, *common felspar*, or *potash-felspar;* a silicate of alumina and potash.
2. *Albite* or *soda-felspar;* a silicate of alumina and soda.
3. *Oligoclase;* a silicate of alumina and soda, but of different proportions to albite.
4. *Labradorite*, *Labrador-felspar*, or *lime-felspar;* a compound of silicate of alumina, silicate of lime, and silicate of soda; distinguished by its cleavage and iridescence.
5. *Anorthite;* very similar to Labradorite, but having part of the lime replaced by potash, soda, or magnesia.

The *Hornblendic* groups of minerals are essentially silicates of magnesia mixed with silicates of lime, iron, or manganese. The two most important minerals are hornblende and augite, which are probably only different states of the same mineral. They differ from one another in crystalline form, and in their "cleavage;" that is, the crystals differ in the direction in which they can be *cleaved* or broken by a blow from a hammer or chisel. As ordinarily seen in igneous rocks, both hornblende and augite appear as grains, crystals, or masses of different shades of olive-green, often so dark as to be nearly black. Unless occurring in moderately large crystals, it is a matter of great difficulty to distinguish hornblende from augite, except by a careful chemical analysis.

In spite of the above-mentioned differences, there is reason to believe that hornblende and augite are merely different forms of the same mineral, the former being produced by very slow, and the latter by rapid cooling. The grounds of this belief are as follows:

a. Hornblende and augite do not differ much in chemical composition.

b. The two minerals are rarely associated together in the same rock.

c. Crystals are found which have the external *form* of augite with the *cleavage* of hornblende.

d. When found together, the hornblende occurs in the mass of the rock; while the augite is only found in the form of crystals lining cavities, where the rate of cooling may have been very rapid.

e. When hornblende is artificially melted in a furnace, it invariably takes upon cooling the crystalline form of augite.

All volcanic and trappean rocks may, then, be regarded as variable mixtures of the felspathic and the hornblendic minerals. Of the many varieties produced in this way, it is essential to know the names of some of the more important; and it will greatly conduce to clearness of ideas on this subject if we hold in remembrance the distinction formerly laid down as to the two great groups of igneous products. Whether we are dealing, namely, with the products of modern volcanoes, or with the more ancient traps, we have to consider two sets of rocks: 1. The melted rocks which are ejected from volcanic orifices as currents, and which subsequently solidify into horizontal sheets, or tabular masses, or vertical dikes; and 2. The mechanical accompaniments of every eruption, in the form of ashes, scoriæ, and breccias.

Holding this distinction in remembrance, the volcanic and trappean rocks fall naturally into two sections each, according as they exhibit a predominance of felspathic or hornblendic minerals. Applying the term "lava" as a general designation to the molten matter which flows in currents from a modern volcano, the *felspathic lavas* are those which exhibit a predominance of felspathic minerals, sometimes to the total exclusion of hornblendic matter. They are often called *trachytes* (Gr. *trachus*, rough), from their rough and gritty feel to the touch. The color of trachyte varies, but it is mostly some shade of blue; and it is usually porous or cellular. When distinct crystals of felspar or any other mineral are present, disseminated in a general felspathic paste, it is said to be "porphyritic;" and, when the rock is vitreous or glassy in texture, from rapid cooling, it forms what is called "obsidian," or "volcanic glass." The second group of lavas is that of the *augitic lavas* or *dolerites*, consisting of some felspar (generally lime-felspar), intermixed with augite, and with small quantities of less important ingredients. The most important member of this group is "basalt," a compact, apparently homogeneous, black, or nearly black rock, with a dull fracture, and sometimes with scattered crystals in it.

The mechanical accompaniments of modern lavas are:

1. *Volcanic tuff* or *ash*, consisting of ashes or powder mixed with small fragments of lava projected from a volcanic orifice during an eruption. It varies from the finest and most impalpable powder up to a coarse breccia containing angular or partially-rounded fragments of lava of all possible sizes.

2. *Scoriæ*, produced by the action of gases upon basaltic or doleritic lavas, and having very much the appearance of cinders of a reddish-brown or black color.

3. *Pumice*, a light, spongy substance, produced by the action of gases upon felspathic or trachytic lavas, and perhaps upon other lavas as well.

The *trappean* rocks, like the preceding, admit of division into two primary sections, the felspathic traps or felstones, and the hornblendic traps, greenstones, or diorites. The felstones are characterized by the predominance of felspar, and are the most highly siliceous, and consequently the most intractable and infusible of all the traps. No general description can be given of the numerous varieties of felstone. The hornblendic traps, or diorites, are those which consist of a mixture of hornblende and felspar. They vary much in appearance and texture, being sometimes fine-grained and granular, sometimes coarsely crystalline. The most important varieties are greenstone, melaphyre, and basalt, this last being just as often a trap as a volcanic rock.

The mechanical accompaniments of the trappean rocks are:

1. *Felspathic ashes*, corresponding to the ashes of modern volcanoes, and like them varying in texture from the finest grain up to the coarsest breccia. As most of the trappean eruptions were probably submarine, many felspathic ashes are regularly bedded and laminated.

2. *Greenstone ashes* and *breccias*, differing from the preceding, in accompanying flows of the hornblendic traps, and in containing, therefore, more hornblende. This gives them a darker tinge, but they are extremely variable both in color and texture.

Though it is convenient to divide the volcanic and trappean rocks into the preceding great sections, it must not be forgotten that in nature there are many gradations between the felspathic and hornblendic lavas and traps. It is a very useful distinction whereby to give a general classification of any trap or lava we may happen to have to deal with; but it is often difficult or impossible to make out in the field whether a given lava or trap belongs to the felspathic or to the hornblendic group.

There still remain two terms which it is essential to comprehend, as they are applied in a general sense to any igneous rock which possesses the necessary characters, whether it be volcanic or trappean:

1. Whenever any lava or trap consists of a compact, earthy base, in which are scattered distinct crystals of any mineral (such, for instance, as felspar or hornblende), the rock is said to be "*porphyritic.*" In common language, the rock, in these cases, is often spoken of as a "porphyry;" but this had better be avoided. The name porphyry has been employed to designate more than one special rock; and it prevents confusion, therefore, if, instead of saying that a rock is a porphyry, we speak of it as a porphyritic felstone, or greenstone, or whatever it may be.

2. Any lava or trap may become an "amygdaloid," or be *amygdaloidal.* This term comprises all those igneous rocks in which we now find round or almond-shaped nodules of any mineral, such as calcspar or quartz, disseminated through a matrix of ordinary lava or trap. The origin of this structure is readily comprehended. As the molten rock is being forced up the interior of a volcano, it becomes impregnated with various elastic gases. The expansion of these causes the formation of numerous bubbles or cells in the melted mass, just as can be seen any day in the slag of a furnace. As the lava flows along, the cells or cavities thus produced become drawn out or lengthened in the direction of the current, so as to often assume the shape of an almond; hence the name "amygdaloid" (Lat. *amygdala*, an almond). In most modern lavas, and in some traps, these cavities or cells remain empty, and are seen to be lined by a vitreous glaze or varnish; and the whole rock becomes cellular. In some lavas, however, and in many traps, the rock has, at some later period subsequent to its cooling, been subjected to the percolation of water holding in solution certain mineral substances, of which carbonate of lime and silica or flint are the commonest. These dissolved materials are gradually precipitated from the water and deposited in the cells of the rock; till finally, in place of the original empty cavity, you get a nodule of some mineral, such as calcspar, agate, or chalcedony. Sometimes, however, the cell has been partially filled with one mineral, and partially with another, and very generally some of the cells of an amygdaloid will contain one mineral, and other cells will be filled with a different mineral.

CHAPTER IX.

PLUTONIC ROCKS.

WE have next to consider the composition of the crystalline plutonic rocks, which, as already said, are believed to have been formed by igneous or hydro-igneous action at great depths below the surface of the earth, and under enormous pressure. The most important plutonic rock is granite, but there are some others of which it is necessary to know the characters and composition.

I. *Granite* is a crystalline rock, in which the crystallization is confused; that is to say, there is rarely any regular arrangement of the crystals, but they are confusedly scattered in every direction through an uncrystallized matrix. When, as sometimes happens, one of the materials of the granite has crystallized in large crystals, more conspicuous than any of the rest, the granite is said to be "porphyritic." Granite is ordinarily composed of three minerals—quartz, felspar, and mica—the proportions of which vary in different granites, and often in different parts of the same granitic mass.

The *quartz* is usually one of the most abundant of the elements of granite, but it does not generally occur in distinct crystals, and it may be present in only small quantity. Being merely silica or flint, the quartz may be picked out by its appearance, and by its not being capable of being scratched with the point of a knife. As a general rule, the quartz forms a glassy mass in which the other elements of the granite have confusedly crystallized.

The *felspar* is generally present in more than one of its forms, and it is the most conspicuous crystalline element of the granite. Ordinarily, only part of the felspar has crystallized, and the remainder is either amorphous, or has crystallized in very small crystals. The commonest felspar of gran-

ite is potash-felspar or orthoclase, and one of its commonest colors is pink or flesh-colored.

The *mica* is usually present in the form of small, glistening scales, either white or black in color, or sometimes brown, green, or yellow. It more rarely occurs in the form of large tabular plates. Mica is essentially a silicate of alumina combined with the silicate of an alkali; and, when this alkali is potash, we get the commonest form of mica.

The most remarkable point about the crystallization of granite is that the more infusible and intractable portions of the mass have crystallized or consolidated last, and the most fusible have consolidated *first*. In melting granite, the quartz would melt last, as being the most infusible, and requiring the highest temperature before it would melt. This being the case, it is quite clear that in the cooling of granite the quartz ought to have consolidated *first*, and the more fusible felspar and mica should have remained fluid for a longer period. The reverse of this, however, is what has really occurred. The felspar and mica have crystallized first, and they are found now in hard, transparent, glassy quartz, which must have remained fluid to the last, as shown by its often retaining accurate casts of the imbedded crystals. Sometimes, however, the quartz and felspar have crystallized at the same time, and have mutually impressed their forms upon each other. It is very difficult to explain this undoubted general fact in the crystallization of granite. The most probable explanation is based upon certain experiments which seem to show that melted silica in cooling has the property of remaining for some time in a soft, *gelatinous* condition, whereas this is never the case with felspar.

There are, however, many grounds for believing that the conditions under which granite was formed, were conditions in which *water* played quite as important a part as *heat*. It has, in fact, been asserted, apparently upon insufficient grounds, that granite has never been fused; because the specific gravity of its quartz agrees with that of silica precipitated from a watery solution and not with that of silica which has cooled after igneous fusion. The quartz of granite, also, often contains microscopical cavities with fluid in their interior, showing that water was certainly present at the time of its formation. Almost all modern lavas, however, show these same cavities; so that this cannot be advanced as an argument against the belief that granite has been at one time fused. This appears also to be established by the crystallization of granite, by the

baking and metamorphizing effect which it exercises upon the other rocks with which it comes in contact, and by its sending out veins into the surrounding formations. At the same time, there is strong reason to believe that very many granites are the result of the alteration and semi-fusion of other rocks *in situ*, and that in many cases these rocks were primitively stratified rocks. Thus, granite sometimes passes insensibly into gneiss, which was certainly at one time an ordinary stratified rock. Some granites, therefore, may properly be considered as *metamorphic* rocks; but it is not certain that this explanation will apply to all granites.

II. *Syenite* is in all its geological features identical with granite; but, instead of consisting of quartz, felspar, and mica, it is composed of quartz, felspar, and hornblende. When extensively developed, syenite frequently loses its quartz, and then passes into syenitic greenstone or felstone-porphyry.

III. *Protogine* or *talcose granite* is similar to granite, except that it consists of quartz and felspar, with talc in place of mica. The composition of talc is a silicate of magnesia.

IV. *Eurite* is simply granite in which all the component minerals—quartz, felspar, and mica—are mingled together so as to form a finely-granular mass, not exhibiting the coarse and distinct crystallization of ordinary granite.

PASSAGE OF GRANITIC ROCKS INTO TRAP.—It has already been mentioned that ordinary granite may pass into gneiss. Similarly protogine may pass into talcose schist. These facts support the view that some granites are of metamorphic origin, and are to be regarded as the extreme term of the metamorphic series. On the other hand, granite and all its varieties sometimes pass by insensible gradations into ordinary trap-rock. This would strongly support the view that *some* granites are truly of igneous origin.

CHAPTER X.

METAMORPHIC ROCKS.

THE true metamorphic rocks are almost always devoid of organic remains, and contain no distinct fragments of other rocks, whether angular or rounded. As before remarked, they are believed to have been produced by an alteration or metamorphism of ordinary stratified rocks, in consequence of the action of heat in conjunction with moisture, under great pressure. The most important metamorphic rocks are gneiss, hornblende-schist, mica-schist, roofing-slate or clay-slate, quartzite, and primary or metamorphic limestone.

I. *Gneiss* in its mineral composition agrees with granite, being composed of quartz, felspar, and mica; but these materials, instead of being confusedly crystallized together, are arranged in thin layers, along which the rock has a tendency to split. As a rule, each of these layers consists of one of these minerals; and thus a layer of quartz succeeds a layer of felspar, and this is followed by a layer of mica, and so on in indefinite alternation. These layers of different mineral composition are called "folia," and the rock is said to be *foliated.* The origin of foliation will be subsequently considered; in the mean while it is sufficient to remark that the "folia" of the rock, though of different color, texture, and mineral composition, are *not* the original laminæ of deposition. It may happen, as a matter of accident, that the lines of foliation agree with the lines of stratification or lamination; but it is much more general for the lines of foliation altogether to disregard the original planes of stratification.

If hornblende replace the mica of gneiss, or be present in addition to the quartz felspar and mica, the rock becomes a "syenitic gneiss." If talc take the place of mica, the rock is said to be a "talcose gneiss," or sometimes a "stratified protogine."

II. *Hornblende-schist* differs little from "syenitic gneiss." It is a foliated rock, nearly black in color, composed principally

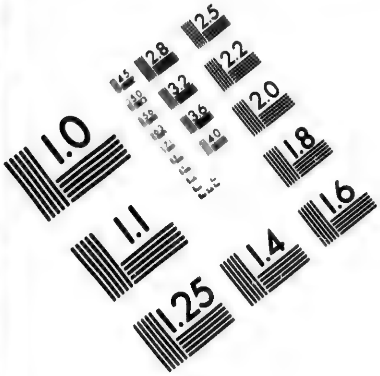
of hornblende, with a variable quantity of felspar, and sometimes with grains of quartz.

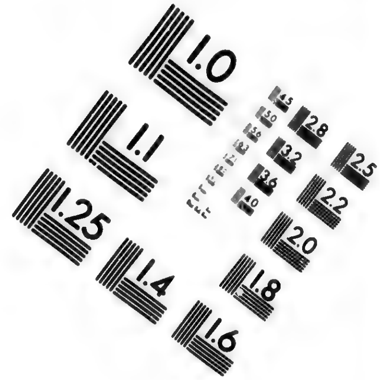
III. *Mica-schist* is another foliated rock, of very common occurrence. It consists of alternating layers or folia of mica and quartz; the mica being sometimes so abundant as to constitute almost the entire rock.

IV. *Clay-slate* or *Roofing-slate* is nothing more than ordinary laminated clay or shale, which has been so far metamorphosed that the rock will no longer split along the original lines of stratification, or does so with great difficulty; whereas it will split readily and indefinitely along a second different set of planes, usually altogether discordant with the original laminæ of deposition. This structure is called "cleavage," the rock is a *cleaved* rock, and the lines along which it splits are known as "cleavage-planes." The nature and origin of cleavage will be considered later on; in the mean while it must be remembered that all slate is not a metamorphic rock, in any other sense than that cleavage is never present in a rock in the time of its deposition, but is always induced in it at some later period, in consequence of some external agency. In this general sense, slate is certainly always a metamorphic rock; but there are many more oı less perfect clay-slates in the ordinary fossiliferous rocks; and there is no positive test by which such slates can be distinguished from the clay-slates which occur in the series of the metamorphic rocks.

V. *Quartzite* or *quartz-rock* is produced by the metamorphism of ordinary siliceous sandstones, which have been so far melted that the component grains of quartz have their original sharpness of outline blurred, and have been fused together at their edges. Excellent examples of quartzite may be found in sandstones near their point of junction with trap dikes; or in the sandstone-slabs which are sometimes used as bottoms for the hearths of iron-furnaces. Under no circumstances must *quartzite* be confounded with *quartz;* the latter being a mineral which occurs under many forms, while the former is a half-melted sandstone.

VI. The last metamorphic rock of any importance is *primary limestone* or *metamorphic limestone*, as it would be better termed. This occurs either in the form of thin foliated beds, not at all unlike certain varieties of gneiss, or sometimes as a massive, white, granular marble. In this latter case, the rock has lost all traces of bedding and is highly crystalline. When not colored by foreign substances, as it very often is, it is called "statuary marble," as it is largely used in sculpture.





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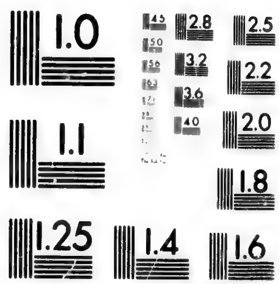

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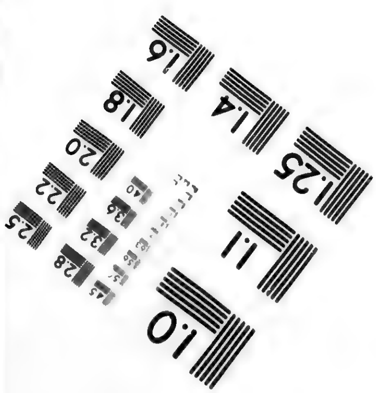

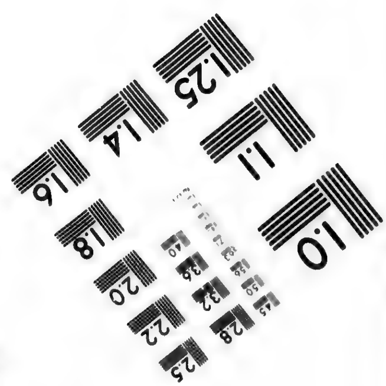

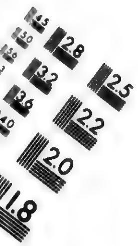
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CHAPTER XI.

DIVISIONAL PLANES OF ROCKS.

BEFORE going on to consider the manner in which the four great classes of rocks present themselves in the field, it is necessary to study the various lines and planes along which any given rock may be split, or exhibits a natural fissure. All these lines and planes are spoken of in geological language as the "divisional planes" of rocks; and there are four kinds of these, the nature and origin of which it is absolutely necessary to understand.

I. PLANES OF DEPOSITION OR STRATIFICATION.—These are the original lines and planes marking the boundaries of the different layers or strata of which every stratified or "bedded" rock is composed. Strictly speaking, the "planes of stratification" are the planes which divide an aqueous rock into its different beds or strata; while the "laminæ of deposition" are the lines which divide each stratum into its minor laminæ or layers. *Strata*, varying in thickness from a few inches up to several feet, are the characteristic of every sedimentary rock. The *laminæ* vary in thickness from one inch down to the thinness of writing-paper, but they are not universally present. In many cases a rock—as, for example, chalk—may exhibit more or less clearly the original lines of stratification, but shows none of the minor laminæ of deposition; while sometimes even the former may be obscure or obliterated. The lines or planes which divide one lamina from another indicate pauses in the work of deposition. The lower layer had time to harden somewhat before the succeeding layer was deposited; hence the rock splits naturally along the lines between the layers, since there is here less cohesion than elsewhere. The lines of stratification indicate still longer pauses in the work of deposition. The lower stratum had so much time

allowed it to consolidate in, before the upper layer was deposited, that there is a total want of cohesion between the two, and two succeeding strata are separated by an actual break of continuity.

II. PLANES OF JOINTING.—The second class of divisional planes comprises a group of fissures which are known as "joints," and are found in all rocks alike, whatever the nature of these may be. If it were not for the presence of joint-planes, the unstratified rocks, such as basalt or granite, could not be quarried, since they would form undivided, intractable masses of solid rock (Fig. 17).

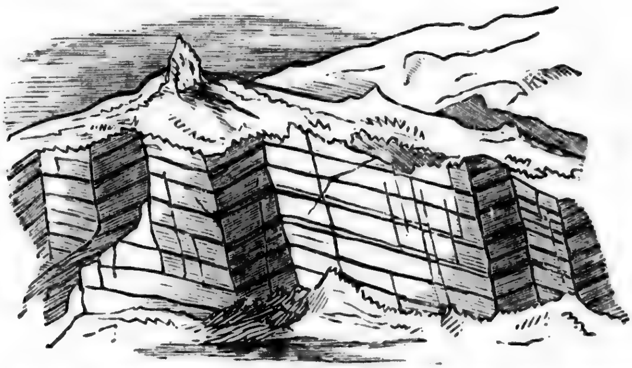


FIG. 17.—Joints in limestone (after Jukes). The faces of the joints which coincide with the dip are shaded; those of the joints which run along the strike are unshaded. The nearly horizontal lines are the lines of stratification.

As a matter of fact, then, all rocks are traversed by a series of divisional planes or "joints," which divide the rock more or less completely into a series of blocks of different sizes and shapes. In stratified rocks, joints are generally inclined at angles more or less nearly perpendicular to the planes of stratification or bedding; and many of them are extremely irregular in direction. Often, however, there may be made out two leading systems of joints, of which one series coincides with the direction of the inclination or "dip" of the beds, while the other series runs nearly at right angles to the former. When these two sets of joints are well developed, as they often are in limestones (Fig. 17), they divide the entire mass of the rock into a series of rectangular blocks, the upper and lower surfaces of which are formed by the planes of stratification, while the sides are formed by the joints. The planes of jointing are generally most close, regular, and even, in the

finer-grained rocks, and more irregular and uneven in the coarse-grained rocks.

The most common and general cause of jointing appears to be the contraction of the rock in the process of consolidating. All rocks, in passing from an unconsolidated to a consolidated condition, undergo a certain amount of contraction, and it appears impossible that this contraction can take place in any large mass of rock without the production of numerous fissures or joints. That the power which produced joints acted with great force, is shown by joints traversing conglomerates, which often cut clean through the hardest pebbles as well as the softer matrix.

In the solid igneous and plutonic rocks the joints are generally very irregular, but they are sometimes so closely set and so regular as very closely to simulate bedding. There is another case of regular jointing which is often seen in lavas and traps, and which requires explanation. This is the *columnar* jointing of traps and lavas, by which the entire mass of the rock is divided into a series of columns, which have a more or less perfect hexagonal outline, thus forming six-sided prisms (Fig. 18). This structure is seen in its greatest perfection in the Giant's Causeway on the northeast coast of Ireland, and in the "pillared" island of Staffa, on the west coast of Scotland.

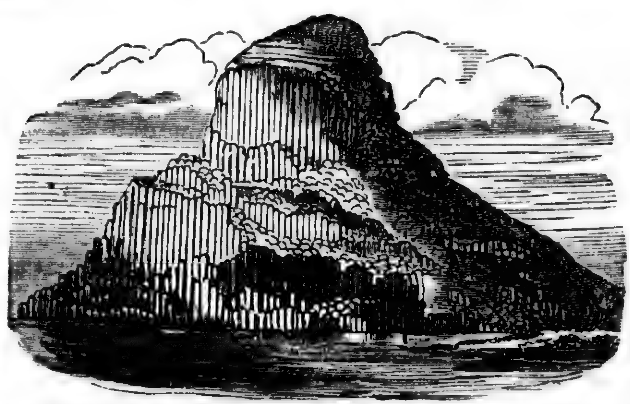


FIG. 18.—View of the Island of Cyclops, in the Bay of Trezza, showing columnar lava.

There is one general law which holds good without exception in these columnar masses. *The direction of the columns is invariably perpendicular to the cooling surfaces of the melted mass.* Thus, if you have a mass of basalt included between stratified rocks (Fig. 19, *a*), the direction of the columns will

be at right angles to the surfaces of the stratified beds, since it was at these surfaces that the basalt commenced to solidify. If the basalt has formed a vertical dike or wall-like mass intersecting other rocks (Fig. 19, *b*), then the direction of the columns will be horizontal, or at right angles to the sides of the dike. Lastly, if the melted mass has formed a kind of pipe

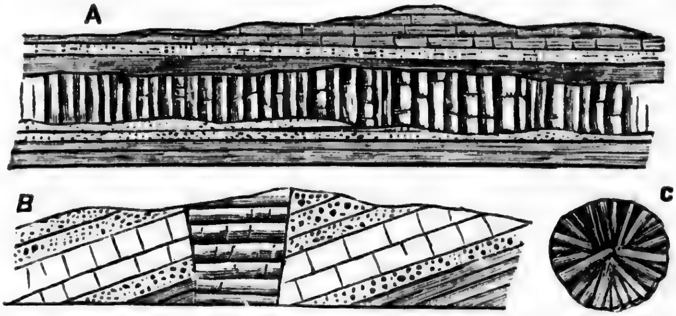


FIG. 19.—*a*, Columnar basalt lying between horizontal beds of aqueous rock; *b*, Columnar dike, intersecting stratified rocks vertically; *c*, Columnar trap filling a pipe in aqueous rocks, and shown in cross-section. The direction of the columns in these three figures is seen to be at right angles to the surfaces of cooling.

running through other rocks (Fig. 19, *c*), then the direction of the columns will be like the spokes of a wheel, radiating in every direction from the centre to the circumference.

In most cases, the columns are of considerable length, varying from five or six feet up to as much as one hundred or one hundred and fifty feet, with a diameter of from six to eighteen inches, and only interrupted by an occasional cross-joint. In other cases, the columns have a diameter of several feet, and their outline is only rudely hexagonal; so that the columnar structure of the rock can only be perceived on a large scale, and when looked at from a distance. Lastly, there are cases in which the columns are divided into a number of short hexagonal masses, the ends of which are occasionally developed into ball-and-socket articulations or joints. The origin of these "articulated" columns has been shown by experiments made upon artificially melted basalt. If such a melted mass be allowed to cool *slowly*, it returns to its original stony condition. In cooling, however, numerous points of aggregation or centres of solidification appear in the mass, and the solidifying particles arrange themselves round these, so as to form a number of concentric coats round each centre, somewhat like the coats of an onion. The final result of this is, that the

whole mass comes to be composed of a number of spherical balls, each of which is composed of a series of concentric coats. If all the balls are of equal size, each will be touched by exactly six others; and, if all the balls tend to increase equally in size at their circumferences, each will ultimately be squeezed, by the pressure of the others, into an hexagonal prism. This, there is every reason to believe, is what has actually occurred in the case of articulated columnar basalt. Indeed, the tendency to form spheroidal balls, composed of many concentric coats round a central nucleus, is observable in many igneous rocks, without its ever going so far as to produce a columnar structure. It occurs in many granites and perhaps in most traps, but it is rarely to be detected except upon surfaces which have been long weathered.

III. Planes of Cleavage.—The structure, characters, and origin of cleavage-planes are of the greatest interest and importance; and few subjects require greater practical experience in the field than to distinguish readily and with certainty between cleavage and lamination. Cleavage-planes—like the planes of foliation—are what are called "superinduced" planes of division. That is to say, they are not original divisional planes, connected with the mode of formation of the beds, like the planes of stratification and lamination; nor are they merely resultant upon the passage of the beds from an incoherent to a solid condition, like the planes of jointing. They are *superinduced* upon the rock *at some time subsequent to its deposition and solidification;* and as a rule they altogether ignore and disregard all the original divisional planes. As the cleavage-planes are thus superinduced, it follows that they occur most commonly in metamorphic rocks, or in the older stratified rocks which have been subjected to the greatest changes since the time of their original deposition. Cleavage, however, may, and does, occur in rocks of all ages.

By *cleavage*—or, as it is sometimes called, "slatyc leavage" —is understood a tendency of any rock to split into an indefinite number of thin layers or plates, which have a certain definite direction over wide areas, wholly independent of the original lamination or stratification of the rock. Cleavage differs from jointing in this: The mass of rock included between any two joints has no tendency whatever to split again in a direction parallel to the planes of the joints; whereas in a cleaved rock the mass is capable of being indefinitely split or subdivided in the direction of the slaty cleavage. As a rule, not only do the cleavage-planes altogether ignore the

original lines of lamination (Fig. 20); but the result of cleavage is positively to seal up the original planes of deposition. A cleaved rock will not only split most easily in the direction

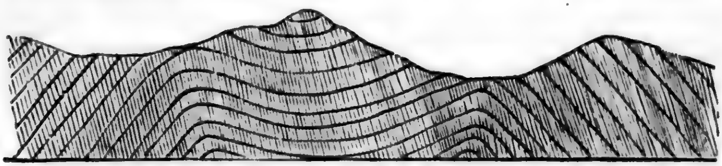


FIG. 20.—Diagram to illustrate cleavage. The dark lines indicate the bedding of the rock, and the fine lines indicate the cleavage-planes. The latter are seen to maintain a uniform direction, while the strata are contorted.

of the cleavage-planes, but it is impossible, or very difficult, to get it to split along the original lines of lamination. The original layers of deposition may, nevertheless, be usually detected without much difficulty. In the case of fossiliferous cleaved rocks, they may usually be made out by the occurrence of lines of fossils. In the case of ordinary roofing-slate, in which this test is useless, the original lines of bedding or lamination are marked by a number of parallel stripes, some of which are lighter, and others darker, than the general mass; while they differ from one another in grain and texture. This constitutes what was termed by Sedgwick the "stripe" of the slate (Fig. 21).

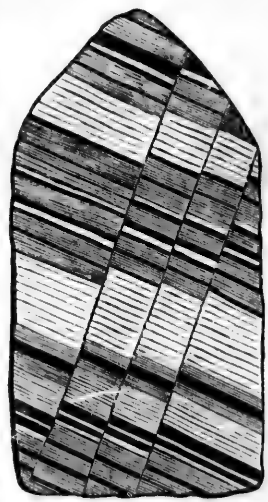


FIG. 21.—Striped and faulted slate from the north of England. The rock is a cleaved volcanic ash, and the face figured is a plane of cleavage. The lines running across it are the "stripe," and are the original lines of lamination. The specimen is traversed by three parallel "faults," by which the original layers have been slightly displaced.

The finer grained any rock may be, the closer and more regular are the planes of cleavage; the coarser the rock, the fainter, wider apart, and more irregular are the cleavage-planes. It follows from this that cleavage is only seen in its highest perfection in the finer argillaceous rocks, such as shale; though it occurs also in sandstones and limestones, and is often well developed in volcanic or trappean ashes. The moment, however, that a shale is subjected to cleavage it ceases to be a *shale*, and becomes properly a *slate*. The term "slate" is often loosely applied, but it ought to be restricted

to *cleaved* rocks; though what is commercially called slate is often obtained from stratified rocks which are not cleaved. The best roofing-slates, however, such as the Welsh slates, are cleaved rocks; and the flat surfaces of the slate are not the original layers of the rock, but are planes of cleavage, and generally cut the original laminæ of deposition at high angles.

The remaining phenomena with regard to cleavage which require notice, are these:

a. The direction of the cleavage-planes is generally constant in any given district, retaining the same general direction, or "strike," over widely-extended areas, and through whole mountain-chains.

b. The cleavage-planes, as already remarked, generally disregard the original lines of deposition. As a matter of chance, the planes of cleavage may happen to coincide with the bedding; but, as a rule, they maintain a steady direction wholly irrespective of the original stratification or of subsequent contortions of the rocks (Fig. 20).

c. The general direction, or "strike," of the cleavage-planes usually agrees more or less closely with the strike of the stratified rocks of the district; but the inclination, or "dip," of the cleavage-planes is altogether independent of the "dip" of the beds.

d. Lastly, in all cases where the cleavage-planes are well developed, they can be shown to have produced a fresh arrangement of the minutest particles of the rock through which they pass. Thus, if a fine-grained slate be carefully examined, it is found that all the longer particles of the rock are lying with their longer axes coinciding with the dip of the cleavage. This rearrangement is shown more obviously in cases where the cleaved rock contains fossils. In all such cases it invariably happens that the fossils are *distorted*, being lengthened or drawn out in the direction of the cleavage, and contracted in the opposite direction, or at right angles to the cleavage.

Origin of Cleavage.—By Prof. Sedgwick, who was the first thoroughly to examine the phenomena of the slaty rocks, cleavage was referred to the action of crystalline or "polar" forces, acting in given directions upon large masses of a nearly homogeneous mineral nature. Recent experiments, however, appear to have demonstrated that cleavage is the result of great compression of the rock, exercised *laterally*, or in a direction at right angles to the direction of the cleavage-planes themselves. The effect of this powerful lateral pressure is to

compress all the particles of the rock in a direction at right angles to the cleavage-planes, and to pull them out or lengthen them in the opposite direction, *or in the same direction as the cleavage.* The result of this is, that the whole mass cleaves or splits in a direction at right angles to the line in which the pressure is exerted. A further result of the pressure which produced the cleavage is, that the cleaved rock is condensed and compressed to an amount averaging about one-half of its original volume.

The correctness of this theory as to the origin of cleavage has been shown by actual experiment. Thus, Mr. Sorby showed that if a mass of clay were taken and mixed confusedly with a number of scales of oxide of iron, and if the whole were then reduced to half its original volume by pressure, the entire mass would exhibit cleavage in the most perfect manner, *splitting with great ease in a direction at right angles to the line in which the pressure had been applied.* Not only so, but the particles of oxide of iron were found to have arranged themselves so that their longer axes universally coincided with the direction of the cleavage. Subsequently, Dr. Tyndall showed that pressure alone would produce cleavage in perfectly homogeneous substances, without the presence of particles having flat surfaces, such as scales of oxide of iron. Pure clay or white wax thus submitted to pressure became perfectly cleaved, splitting indefinitely into thin laminæ in a direction at right angles to the line in which the pressure had been applied. There can, therefore, be no hesitation in accepting the theory as to the origin of cleavage in consequence of lateral pressure. The *cause* of this lateral pressure will be spoken of in considering the cause of contortions and faults.

IV. Foliation.—The last class of divisional planes of rocks comprises what are known as the planes of "foliation." Foliation, like cleavage, is a *superinduced* structure, brought about upon the rock at some period subsequent to its deposition or solidification; and it is only known to occur in rocks which either belong to the metamorphic class, or can be shown to have been locally metamorphosed by some neighboring mass of melted rock. In many respects foliation agrees with cleavage. The planes of foliation are divisional planes along which the rock can be split, and which preserve a uniform direction over more or less extensive areas, wholly independent of the original lines of stratification or lamination. In a cleaved rock, however, there is no perceptible mineral distinction between one cleavage surface and another, or only

rarely, and then to a limited extent. In a foliated rock, on the other hand, the rock is positively separated into a number of thin layers or *folia, which differ from one another in mineral composition.* Gneiss, for instance, is a foliated rock, and it consists of a number of thin layers of quartz, felspar, and mica, alternating with one another indefinitely. As regards nomenclature, while a cleaved rock should always be spoken of as a "slate," or a "slaty" rock, a foliated rock should always be termed a "schist" (Gr. *schizo*, I separate). The term "schist," however, is sometimes loosely applied to rocks which have no foliated structure.

The planes of foliation may accidentally coincide with the original lines of lamination, or bedding, but, as a rule, they resemble cleavage-planes in being wholly independent of the original stratification of the rock. The planes of foliation, however, in a given region very often agree in direction with the cleavage-planes of other rocks in the same district. This fact has led to the opinion that foliation is merely a further development of the process of cleavage. This view was originally put forth by Sedgwick, and has been supported by Darwin in his observations on the metamorphic rocks of South America. It is difficult, however, to see how any amount of pressure could produce a rearrangement of the mineral particles of the rock, such as we see in foliation; while there is every reason to believe that cleavage is produced by pressure alone. Accordingly, Sir Charles Lyell and Mr. David Forbes both reject the view that there is any necessary connection between foliation and cleavage; though it cannot be said that any generally applicable explanation has been advanced in its stead.

CHAPTER XII.

CHARACTERS OF AQUEOUS ROCKS IN THE FIELD.

HAVING now considered the four great classes of rocks as regards their mineral characters, structure, and origin, we have now to consider the phenomena which they present when studied in the field. It is hardly necessary to remark that the aqueous rocks are from this point of view by far the most important, and will claim the greatest part of our attention.

Any formation or group of stratified rocks may consist of a single species of rock, or of various different kinds arranged in alternating beds. Thus we occasionally find a series of beds, of many hundreds or even thousands of feet in thickness, composed throughout of similar materials, shale, limestone, conglomerate, or sandstone. More commonly, however, the vertical thickness of any bed or group of beds is not so great, and strata of shale, sandstone, and limestone, alternate with one another with tolerable rapidity.

Lateral Extent of Beds.—Sometimes we meet with a particular bed of rock which is continuous, and preserves the same characters, over very considerable areas. As a rule, however, if we are able to follow out any particular bed, we find that it begins in time to diminish in thickness, and ultimately ceases to exist altogether (Fig. 22). This is what is called technically the "thinning out" of a bed. Each individual stratum, therefore, in any group of beds may be regarded as an unequal mass, thickest in the centre, and gradually thinning out in all directions toward the circumference. What occurs in the case of a single bed, holds good in the case of any particular aggregation or group of beds which we may choose to take. Any group of beds is continuous over a certain area (and the larger the group of beds is, the larger will be the area over which it is likely to be spread), but, however

extensive this area may be, the group will be found ultimately to thin out. What commonly occurs in any group or set of beds is this: If we follow the group for any distance, we find that its characters gradually change by the thinning out of particular beds and the intercalation of others of a different mineral nature (Fig. 22). The ultimate result of this process is, that we get a group of beds which are the geological equivalent of the beds with which we started, but which differ altogether in their nature. An excellent example of this is afforded

FIG. 22.—Diagram to illustrate the thinning out of beds laterally. The beds at *a* are the equivalent of the beds at *b*, but the two are wholly different in nature.

by the Carboniferous limestone of England, and the changes which it undergoes in passing from the south northward. In ths south of England the Carboniferous limestone is a great mass of pure limestone, over one thousand feet in thickness, and not exhibiting a single bed of sandstone or shale. As we go northward, the beds of limestone thin out gradually, and beds of sandstone, grit, or shale, begin to be intercalated; till, when we reach the north of England, we find the formation to be composed of alternating limestones, sandstones, and shales, with a few thin bands of coal, the limestones still bearing a considerable proportion to the whole mass. Proceeding still farther northward, the limestones go on thinning out, till, in Central Scotland, the Carboniferous limestone consists essentially of a great series of sandstones and shales, with thick and workable beds of coal, while the limestones are reduced to a few comparatively insignificant bands. Still, the series is the geological equivalent of the great calcareous mass which represents this formation in Southern England

ORIGINAL HORIZONTALITY OF STRATA.—The under and upper surfaces of any given bed are always approximately parallel to one another. This arises from the fact that, when the bed was in process of deposition at the bottom of the sea, the particles of sediment were driven by the motion of the water to settle in all the hollows and depressions of the surface, where they were least liable to be disturbed by any mov-

ing force. For the same reason all stratified beds have been originally deposited in a horizontal position, or approximately so. As will be seen, however, it is rare at the present day to find stratified rocks in their original horizontality. They are mostly found now to be "inclined," that is to say, they have been acted upon by subterranean forces, and have been tilted up, so as to be inclined to the horizon at angles varying from the perpendicular to nearly absolute horizontality.

Diagonal or Oblique Lamination.—As a rule, the laminæ of any given stratum are parallel to the under and upper surfaces of the stratum. There are cases, however, in which the laminæ of deposition hold a different position, oblique to the general planes of stratification (Fig. 23), and the direction of the laminæ in one stratum may be wholly different from their direction in the contiguous beds. These cases are spoken of

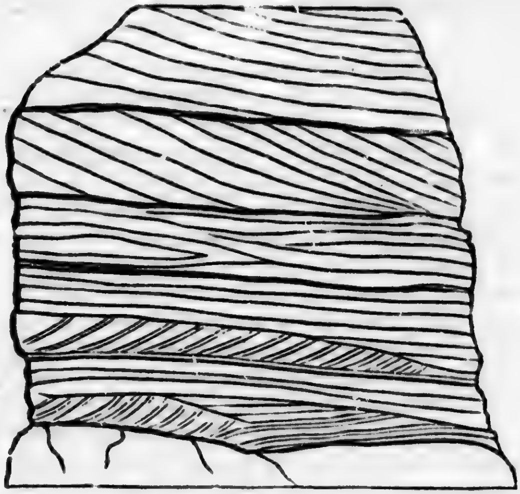


Fig. 23.—Section of false-bedded sand in the greensand-formation in Bedfordshire, England.

as cases of "diagonal stratification," "oblique lamination," or "false bedding." The phenomenon is a common one among sandstones or sands, and is due to the fact that the beds were deposited as shifting sand-banks by means of currents which were constantly changing in direction, and probably in strength as well. False bedding is chiefly of importance as being liable to be mistaken for true stratification in the field. In a small

section it may be impossible to say whether the planes are those of true or diagonal stratification; but, when several sections are compared over a considerable area, there can be little difficulty in determining which of these is really the case. From its mode of production, it follows that false bedding only occurs in rocks which have been laid down in shallow water.

RIPPLE-MARK.—Another common phenomenon of the deposits of shallow seas is "ripple-mark" (Fig. 25). In its appearance and structure this is in every respect identical with the rippled appearance and structure of the rippled surface which occurs upon every sandy sea-shore. It is produced in all cases by the passage of moving water over incoherent

FIG. 24.—Diagram to illustrate the formation of ripple-mark.

sand. The action of the water tends to pile up the sand in little ridges (Fig. 24), which are constantly advancing on one another, in consequence of the grains of sand being successively pushed up the long and gentle slope *a*, *b*—*c*, *d*, till they roll over down the short and abrupt slopes, *b*, *c*—*d*, *e*, where they are temporarily undisturbed and protected. The preservation of ripple-mark is due to the fact that, when the tide retires, there may be sufficient time for the ripple-ridges to partially consolidate, and the returning tide may not destroy them, especially if they are covered with a fine film of clay. On the other hand, the returning tide may bring sufficient sediment to cover up and thus preserve the ripple-mark of the former tide. Ripple-mark is seen in many sandstones, and is often preserved in great perfection. Like diagonal stratification, it implies that the beds which exhibit it were deposited in shallow water.

Often accompanying ripple-mark is a structure known by the name of "desiccation cracks." This consists in the presence of little ridges which cross the surface of the stone in every direction. These are produced in consequence of the original surface of mud or sand having been exposed to the heat of the sun for a sufficient length of time to allow of its shrinking and cracking in various directions, just as may be seen any day in a mass of mud allowed to dry. With the return of the tide all the cracks produced in this way are filled up by the sediment which it brings in; and the result of this

is ultimately to produce in the stone a system of solid interlacing ridges in place of a system of cracks or open fissures.

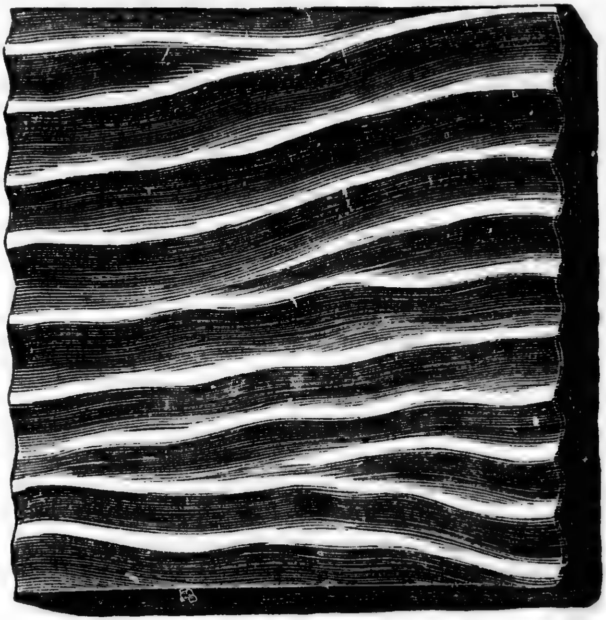


FIG. 25.—Slab of ripple-marked sandstone from the Trias of Cheshire, England.

Not uncommon also in fine-grained sandstones or shales are *rain-prints*, the memorials of ancient showers. These are produced under exactly the same conditions as ripple-marks and desiccation-cracks, and are preserved in the same way. They are produced, namely, upon reaches of sand or mud, which are uncovered by water for a sufficient length of time to allow of their partial consolidation before they are again submerged. They appear in the rock in the form of pits or rounded depressions, each of which has been produced by the falling of a single drop of rain.

PRESENT INCLINATION OF STRATA.—As already remarked, all stratified rocks were originally deposited in a horizontal position, but most of them in the process of elevation to their present situation have been tilted, so that we find them now *inclined* at various angles to the plane of the horizon. In speaking of inclined strata there are several terms which require to be explained.

When a stratum or bed of rock is not perfectly level, but is inclined to one side or other, it is said to *dip* (Fig. 26). The inclination of the bed downward into the earth is called its "dip," the amount of this inclination is called the "angle of dip," and the direction in which the bed is inclined as regards the point of the compass is called the "point of dip," or the direction of the dip. Thus, in the annexed diagram (Fig. 26), the strata are inclined to the horizon at an angle of forty-five degrees, and they dip toward the north; or, in a shorter form, the beds dip N. ∠ 45°.

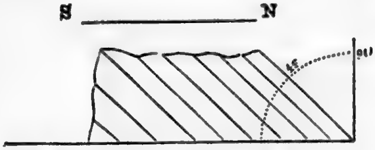


FIG. 26.—Diagram to illustrate the dip of inclined strata.

As inclined strata "dip" or descend into the earth in one direction, they necessarily approach the surface or "rise" in the opposite direction. The place at which an inclined stratum actually comes out at the surface of the earth is called its "outcrop" or "basset." The *line of outcrop* of any given bed or beds, or the line at which it would appear at the surface, supposing that surface to be level, is called the *strike* or "line of bearing" of the bed, or simply its *direction*. The line of strike of an inclined bed is invariably and necessarily *at right angles to the dip*. If, therefore, a bed dips due east or west, its strike will be north and south, and *vice versa*, if it dips north or south, it will strike east and west. When we once know the dip of any bed, we know at once its line of strike, and can tell exactly where it ought to reappear, supposing that it is not interfered with by any interruption. The reverse of this, however, does not hold good; and, if we only know the strike of a bed, we cannot be absolutely certain as to the dip, either as regards its direction or its amount. If we know, for instance, that certain beds strike east and west, we know that they *must* dip at right angles to this; but they may dip either to the north or to the south, and they may be inclined to the horizon at any angle. Whenever beds have no inclination, or are perfectly horizontal, it also follows as a matter of course that they have no strike, since they have no dip. When, again, beds are vertical or perpendicular, they have a strike, and they are said to dip at ninety degrees; but they do not dip in any particular direction. Their strike may be in any direction, but, so long as they are strictly vertical, they cannot dip to any point of the compass.

In all cases of inclined beds (Fig. 27), it follows, as a matter of course, that so long as we walk in the direction of the dip, we must be getting constantly on to higher and higher

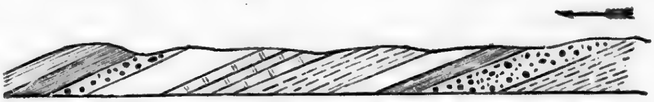


FIG. 27.—Inclined strata. The arrow shows the direction of the dip.

beds. When we reverse our course, and walk in the opposite direction to the point of dip, we are constantly coming upon lower, and therefore older, strata.

CURVED STRATA.—When strata are simply inclined to the horizon at any angle, their dip and strike may be readily made out, and they may easily be mapped and followed across a country. In most cases, however, in Nature, neither the dip nor the strike remains constant over any considerable area. This is due to the fact that most strata in the process of reaching their present situation have been more or less bent and curved; so that they now form portions of curved surfaces, instead of forming straight lines and planes.

When these curves are on a sufficiently small scale to be visible in a single section (Fig. 28), the beds are simply said

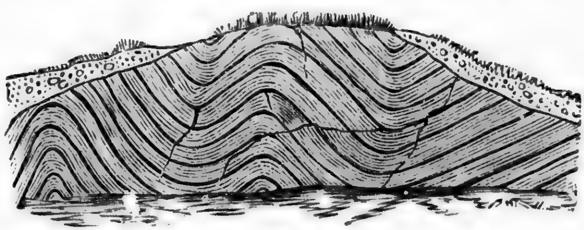


FIG. 28.—Contorted strata of Skiddaw slate in the north of England.—Length of section about sixty feet.

to be "contorted," or "flexured." In these cases, though the contortions may be repeated in small spaces with considerable rapidity, there is generally little difficulty in making out the general dip of the whole set of beds.

When the curves of the beds cease to be upon a small scale, and are more extensively developed, they are no longer spoken of as "contortions." The two chief forms of these major curves are of great importance, since they are of con-

stant occurrence; and they are known as *anticlinal* and *synclinal curves.*

When a group of strata is bent into a curve like a saddle, with its convexity turned toward the surface of the earth, we get what is called an *anticlinal curve* (Fig. 29). The centre

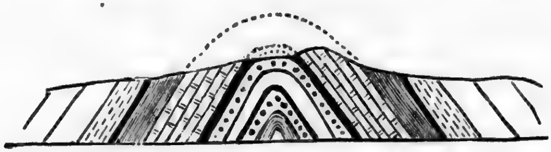


FIG. 29.—Diagram of an anticlinal curve.

of this curve is formed by an imaginary line, called the "anticlinal axis," and the beds necessarily dip in opposite directions on both sides of and away from this line. In any undisturbed anticlinal curve, therefore, there is necessarily a repetition of the strata forming the saddle, and the same beds are found on both sides of the central line. If we commence altogether outside the anticline, and walk toward its centre, at first we pass from newer to older strata, and we find the beds constantly dipping in the opposite direction to that in which we are ourselves moving (Fig. 29). When, however, we reach the centre of the curve, and cross the anticlinal axis, this state of things is reversed. We find now *the same strata*, dipping in the opposite direction to what they were before, or in the same direction as that in which we are moving. Not only is this the case, but the order of the strata is reversed, and we are now passing constantly from older to newer strata.

When an anticlinal curve is arranged not in reference to a line or axis, but to a point, we have what is called a dome-shaped elevation, from the centre of which the beds would dip away in every direction. In this case the strata are said to have a *qua-qua-versal* dip.

A *synclinal curve* is exactly the opposite of an anticline. When the strata are so folded, or curved, as to form a trough, the *concave* side of which looks upward, we have what is called a *synclinal* curve (Fig. 30). The imaginary line which forms the centre of the curve is spoken of as the "synclinal axis;" and the beds necessarily dip inward toward this line upon both sides. In a synclinal curve, therefore, we have a repetition of the strata on both sides of the axis of the curve, but in a reverse manner to what occurs in an anticline.

In the latter the strata dip away from the axis, so that the oldest beds are in the centre of the curve, and the higher and newer beds are removed farthest from the centre. In a syn-

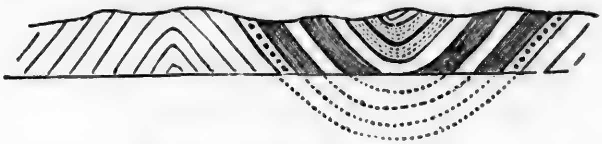


FIG. 30.—Diagram of a synclinal curve.

clinal curve the strata on both sides of the axis are the same, but dip toward the central line; so that the lowest and oldest strata are those farthest removed from the axis, and the newest beds are those in the centre of the curve. In walking, therefore, across any synclinal curve, the beds at first dip in the direction we are moving, and we find ourselves constantly passing from older to newer beds. When we have crossed the central axis we have the same beds over again, but they now dip in the opposite direction to that in which we are walking, and we find ourselves constantly passing from newer to older beds.

FIG. 31.—Diagram to illustrate the formation of contortions.

When the beds of a synclinal are arranged in reference to a single point instead of a line, we have a basin-shaped depression, in which the beds dip upon all sides toward the centre. In other words, the beds have a *qua-qua-versal* dip toward the central point of the basin.

As regards the causes of contortions and curves, the most general cause must be lateral pressure, crumpling up the rocks. The origin of the lateral pressure requisite for this is not altogether clear; but it has been ascribed to the forcible injection of melted rock into fissures in the earth's crust, or to unequal movements of subsidence. A very simple, and apparently adequate, explanation

has, however, been given by Mr. J. M. Wilson, of Rugby, who ascribes contortions to the subsidence of large areas of the crust of the earth. If, namely, we consider a portion of the crust of the earth, *a*, *b*, *c*, and imagine it to sink slowly to the position indicated by the dotted lines in Fig. 31, it is perfectly clear that in so doing its curvature must be reduced, and it must, therefore, be laterally compressed. In this way, the weight of the sinking mass generates sufficient power to crumple up the rocks, so as to accommodate them to their more confined position.

CHAPTER XIII.

UNCONFORMABILITY AND FAULTING.

Unconformability.—When the beds of any group of stratified rocks, or of any two groups, have been continuously deposited, so that they succeed each other regularly without any break or interruption, they are said to be *conformable*. When, on the other hand, there are indications that a break has occurred between the deposition of one set of beds and the formation of the beds which immediately succeed, then the upper beds are said to be *unconformable* to the lower. The most general definition of unconformability which can be given is that when "the base of one set of beds rests in different places on different parts of another set of beds, the two are unconformable to one another" (Jukes). It follows, from this definition, that the essential element of unconformability is, that the lower set of beds shall have been more or less denuded or worn away before the formation of the upper set; so that the upper beds rest upon an uneven and eroded surface formed by the lower beds (Fig. 32).

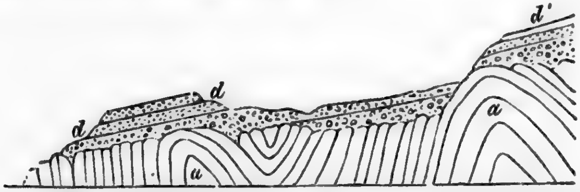


Fig. 32.—Unconformable junction of conglomerates of Old Red Sandstone with Silurian Slates, near St. Abb's Head, Berwickshire.

It does not necessarily result that there is any discordance between two unconformable groups of beds as regards their inclination, especially if both sets are pretty nearly horizontal.

If the two groups of beds are perfectly horizontal, it can still generally be shown that the lower beds have had a fresh surface formed upon them by denudation before the upper beds were laid down upon them. It could, therefore, be shown that the lowest bed of the upper set rested in different places upon different parts of the lower series (Fig. 33, A). If the strata are inclined, and not horizontal, there would usually, but not necessarily, be a difference in the direction of the dip of each set, though this might be very difficult or impossible to detect in a much-disturbed district. However slight this difference might be, it would, however, cause a difference in the strike of the two sets of beds, and the result of this would be that the upper set of beds would "overlap" the lower; that is to say, if followed far enough, the upper beds would be found to rest upon different members of the lower group (Fig. 33, B).

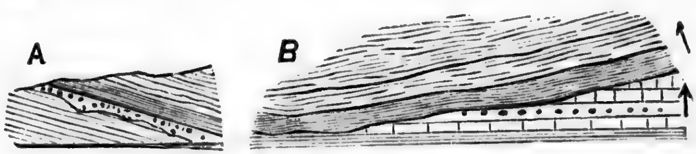


FIG. 33.—A, *Section* of unconformable strata, in which the inclination of the two sets of beds is the same; but the upper beds are seen to rest upon an eroded and denuded surface of the lower beds. B, *Ground-plan* of unconformable strata, in which there is unconformable overlap in consequence of a slight difference in the direction of the dip of the two groups. The arrows indicate the direction of the dip.

As a very general rule, however, when unconformability is present, the upper and lower sets of beds are also discordant with one another as regards their general inclination or dip (Fig. 32). The common thing is to find that the lower group of beds has been uptilted, so that its strata now dip at high angles; that these have been planed down by denuding agents to an approximately level surface; and that the upper beds have been deposited upon the surface thus formed, in such a manner that their dip is much lower and quite different to that of the inferior series.

The sequence of phenomena indicated by this, the commonest case of unconformability, is this: *Firstly*, the lower beds were originally deposited in a horizontal position at the bottom of the sea. *Secondly*, at some time subsequent to their deposition they were raised above the level of the sea, in which process they were *probably* tilted from their former horizontal position, and *certainly* underwent so much erosion

and denudation that they were worn down into a level or nearly level surface. *Thirdly*, they were again submerged beneath the sea by a process of subsidence. *Fourthly*, fresh beds of a different and later age were deposited upon their upturned edges, so as to be altogether discordant in position and inclination. *Fifthly*, and lastly, the whole series composed of the two unconformable groups was again elevated above the sea, so as to occupy the position in which we now find it.

In *all* cases, therefore, the mere fact of unconformability indicates the lapse of an almost inconceivable interval of time, during which the processes just described took place. Even in cases where the two unconformable groups do not differ much in geological age—as where Upper Silurian strata rest unconformably upon Lower Silurian beds—it is difficult to over-estimate the lapse of time indicated by the line of unconformability. Still more vast must be the interval when we find strata of different geological formations in unconformable junction, as, for instance, when rocks of Devonian or Carboniferous age repose upon strata belonging to the Silurian system. And the imagination fails to grasp the period represented by the unconformable juxtaposition of the Palæozoic and Tertiary formations. In many cases the vastness of the time indicated by unconformability may be to a limited extent deduced from what we find has been going on elsewhere during the same period. When, for instance, we find Carboniferous rocks reposing unconformably upon Silurian rocks, we can form some idea of the interval indicated by this, when we know that elsewhere during the period represented by the mere line of unconformability were deposited the odd fifteen thousand feet of strata which make up the Old Red Sandstone, a formation which is properly intermediate between the Carboniferous and Silurian systems. Even without this evidence, we should know that a vast interval must have elapsed; for we should find that the period indicated by the line of unconformability had been sufficiently long to allow of a complete revolution in the life of the globe. We should find, namely, that the animals which peopled the Silurian seas had disappeared, and that their places were taken in the Carboniferous beds by a totally different group of organisms.

A common accompaniment of unconformability, though one by no means necessarily present, is to find a bed of conglomerate at the base of the upper group, containing pebbles derived from the beds of the lower group. Thus, if we found

conglomerates of the age of the Upper Old Red Sandstone resting unconformably upon Silurian strata, we should find that the pebbles in the conglomerate would be of Silurian age. This indicates that, when the lower beds were elevated above the sea, they were worn down into great beds of shingle, and that these constituted the first strata of the upper group, which was ultimately deposited upon the upturned edges of the older set.

OVERLAP.—As has been already pointed out, unconformability is generally accompanied by what is called "overlap;" that is to say, by the extension of one set of beds beyond the ends of another set, so that the upper beds come successively to rest upon different strata of the lower group (Fig. 33, B). This, however, may occur without any unconformability, or without any previous denudation, in cases where the lower group of beds has been from the beginning a mere local deposit of very limited extent. Thus, the Carboniferous limestone (Fig. 34, *a*) is a very widely-extended deposit, which is always conformable to the Upper Old Red Sandstone, when the two occur together. The latter, however (Fig. 34, *b*), is a very local deposit, and has often been laid down in patches which may be of considerable thickness in the middle, but thin out rapidly in all directions. It commonly occurs, therefore, that the Carboniferous limestone overlaps one of these

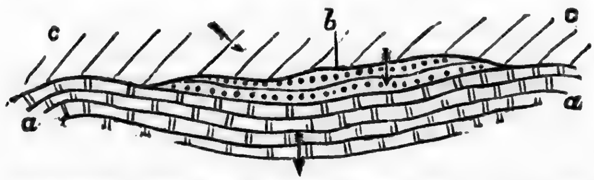


FIG. 34.—*Ground-plan*, showing the Carboniferous limestone (*a*) overlapping a patch of Upper Old Red Sandstone (*b*), and coming ultimately to rest directly upon Silurian strata (*c*). The arrows show the dip. *a* and *b* are both unconformable to *c*.

patches of Upper Old Sandstone, without there being any unconformability; since, when the latter has completely thinned out, the Carboniferous limestone comes, of necessity, to rest upon the beds below the Upper Old Red Sandstone, which beds will probably be of Silurian age.

FAULTS.

We come now to the very important subject of what are known to geologists as *faults* or *dislocations*, the "troubles"

and "shifts" of the practical miner. It has long been recognized that there is some kind of connection between those fissures and cracks in the rocks which constitute faults, and the existence of bendings and contortions of the strata. When the beds have been much folded and contorted, there are usually few fissures of much magnitude, and when the rocks have been much fissured, there are generally few contortions. It is as if the yielding and bending of the rocks under pressure obviated the necessity of their breaking; and when they would not bend, they were forced to break instead. As already remarked, it has been suggested by Mr. Wilson that contortions are the result of the subsidence of a curved area of the earth's crust. The same observer brings flexures into close connection with faults, by further suggesting that faults are the result of the elevation of a curved area of the earth's surface. This view is explained by the following diagram (Fig. 35). If the portion of the earth's crust A B be elevated

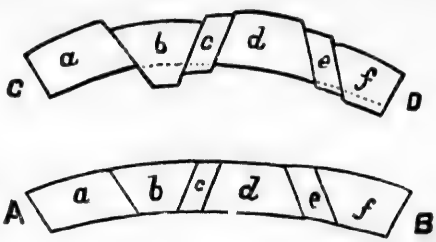


FIG. 35.—Diagram to illustrate the production of faults (after Mr. J. M. Wilson).

so as to assume the more curved form C D, it will be fissured in various places. The masses *a* and *d*, marked out by these fissures, will be pushed up, but the increased space between them will be occupied by the sliding down of the masses *b* and *c*. This view seems to explain fully the production of faults, and has the merit of extreme simplicity.

A *fault* or *dislocation* is a fissure or crack in the crust of the earth accompanied by the elevation of the mass upon one side of the fault, while the other side remains stationary or sinks down. The strata, therefore, upon the two sides of the fault are *shifted* in position (Fig. 36), and no longer are continuous or correspond with one another. If, then, we were following any particular bed, such as a bed of coal (*a*), we should find that its level would be changed where it was intersected by a fault, and that it would be placed higher upon

one side of the fault than upon the other. The amount of difference in the position of any particular bed upon the two sides of a fault, measured vertically, constitutes the "throw"

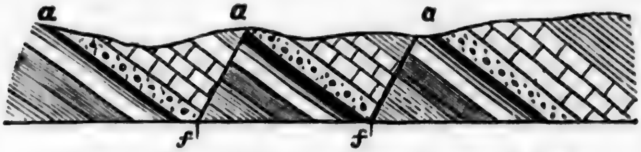


FIG. 36.—Diagram of faulted and displaced strata.—*f f*, Faults.

of the fault; and this throw may vary in amount from a few inches up to many thousands of feet. It need hardly be said that, when the throw of the fault is great, it is not merely a displacement among the beds of a particular formation, but wholly different formations may be brought in contact with one another. In Fig. 37, the line *a b* shows the "throw" or amount of displacement effected by the fault, as measured by the distance between the separated portions of the bed *e*.

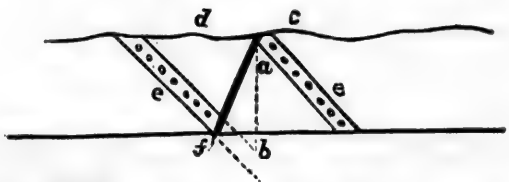


FIG. 37.—Diagram of a fault.—*f*, Fault; *a b*, Throw of the fault; *e e*, Shifted bed; *c*, Upthrow side of fault; *d*, Downthrow side of fault.

The side of the fault upon which the beds are elevated (Fig. 37, *c*) is called the "upthrow" or "upcast" side of the fault; and the side of the fault upon which the beds are depressed (*d*) is the "downthrow" or "downcast" side of the fault. The direction or dip of a fault varies a good deal. Commonly, a fault is vertical. When inclined from the perpendicular, there is one constant rule. The fault dips, or "hades," as it is properly called, in the direction of the downthrow, or under the downcast beds. A reference to Figs. 36 and 37 will show the obvious reason of this, namely, that the upthrow side of the fault could not be elevated if the "hade" of the fault were directed toward it.

The exact line of fault, or, in other words, the original crack along which the strata yielded, is rarely or never seen

now in the form of an open fissure. Either the two sets of beds on the opposite sides of the fault are now in close contact; or, as commonly happens, the original fissure has been completely filled up by the broken-down *débris* and rubbish produced by the grinding against each other of the two sides of the fault; or, lastly, the fault may be filled up with mineral matters of various kinds, constituting mineral veins, or "lodes," which may contain various metals, or may be simply composed of spars of different kinds. It is also readily intelligible that the rocks in the immediate vicinity of any large fault are completely broken up, and disturbed in every possible manner. Not only is this the case, but the faces of the fault itself and the rocks near it are generally polished and grooved, in consequence of the enormous pressure and friction to which they have been exposed. This polished and striated appearance of the rocks near a fault is known to geologists by the name of "slickensides."

In practice, the phenomena presented by a fault vary a good deal from what might be expected from merely theoretical considerations. Theoretically, the upthrow side of any fault ought to form a precipitous hill, while the downthrow side would constitute a plain or a depression (Fig. 38). In

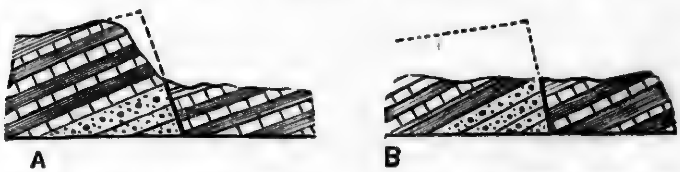


Fig. 38.—A, Section of a fault, showing the upthrow side only partially denuded and still elevated above the downthrow side. B, Section of a fault, showing the upthrow side completely planed down. The dotted lines show the amount removed by denudation.

all cases, in fact, the upthrow side must be elevated above the downthrow side, unless some external agency interfere with this state of things. In practice, however, it is not common to find the upthrow side of a fault remaining in this way as a precipice or mountain; though such cases do occur. In by far the greatest number of cases the country upon the two sides of the fault has been reduced to one uniform level by the denudation of the upthrow side during its slow elevation; so that there is not now the smallest indication upon the surface of any dislocation of the rocks (Fig. 38, B). In these cases, therefore, the chief guide which enables us to discover the

fault is the finding a line with altogether different strata upon its two sides, or with the same strata repeated with the same dip (Fig. 40, A). If we can get anywhere near the exact line of fault, we find "slickensides," along with traces of that breaking up of the beds which necessarily accompanies every large fault. If the beds upon the two sides of the fault belong to the same formation, and if there is no disturbance of the dip, it may be very difficult, or impossible, to make out the fault at the surface of the country. In large faults, however, the beds on the two sides of the dislocation will belong to different parts of the same formation, or to altogether different formations. Thus, the coal-measures, for example, may be "brought down" by a large fault against the lower Carboniferous rocks, or against beds of the Old Red Sandstone, or even against Silurian rocks.

Another phenomenon which enables us to detect a fault traversing inclined beds is what is known as the "lateral shift" in the *outcrop* of any particular bed upon the two sides of the fault; though it is, perhaps, impossible to render this clear by any verbal description. In the first place, no alteration in the line of outcrop can be produced by any fault, except by those which run across the strata, or more or less *at right angles to the strike of the beds.* Even in these cases no change is produced in the outcrop of the faulted beds, if their inclination be vertical. In this case the fault, however great, simply causes the beds to slide up and down upon one another, and, when the two sides of the fault are cut down to the same level, the beds are seen to cross the fault with an unbroken line of outcrop. It is almost impossible, therefore, to detect faults in vertical strata, whatever their magnitude may be. If the beds, however, are inclined, but are not vertical, there is a "lateral shift" in the outcrop of the beds at the point where they are crossed by a fault. If we follow a particular bed across a district, its line of outcrop will be found to agree with the strike of the beds, and will be continuous, if there be no fault. This is shown in Fig. 39, A, where the dotted lines indicate what would be the outcrop of the bed *a*, if it were not crossed by faults. It must be remembered that this figure is a *ground-plan*, and not a *section.* If, however, the bed *a* be crossed by a fault, its line of outcrop is *shifted* laterally, and is found out of its true line of bearing upon the opposite side of the fault. The practical rule about this shift is, that the beds will be *shifted in the direction of their dip upon what was the upthrow side of the fault.* That is to say,

if a bed dipping south, and striking east and west, be crossed by a north and south fault, its line of outcrop will be shifted to the south upon the upcast side of the fault; as is shown in Fig. 39, A. Here the bed *a*, striking east and west,

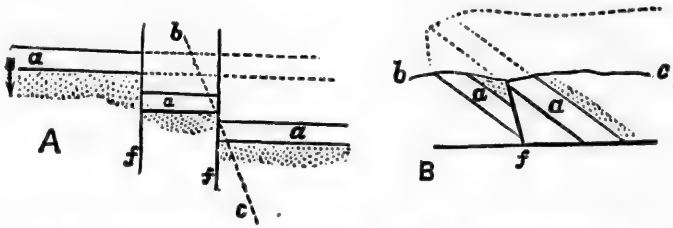


FIG. 39.—A, *Ground-plan* of a bed *a* shifted by two faults (*ff*) which cross it at right angles to its line of strike. The dotted lines show what would have been the line of outcrop if undisturbed. B. *Section* of the same along the line *bc*. The dotted lines show the upthrow side of the fault, and the former prolongation of the bed *a*, before it was planed down by denudation.

and dipping south, is crossed by two north and south faults (*ff*), the upthrow side of which is on the east. The bed *a* is, therefore, shifted to the south on the eastern side of each fault, the amount of shift varying with the magnitude of the fault. The *cause* of this apparent lateral shift is as follows: When the fault originally took place, the upthrow side was elevated above the downthrow side, and there was no shift in the outcrop of any of the strata crossed by it. The bed *a*, for instance, as shown in Fig. 39, B, had its outcrop continuous on both sides of the fault, and was simply elevated on the upthrow side, as is indicated by the dotted lines. If, however, the beds composing the upthrow side of the fault be now cut down by denudation to a level with the downthrow side, it is clear that the outcrop of the beds on the two sides of the fault can no longer correspond. Any particular bed in the upthrow side must be cut across—in consequence of its inclination—at a point removed some distance from its original line of outcrop, the removal being in the direction of the dip of the strata. The larger the fault, the greater will be the distance at which each bed will have to be cut across, in order to reduce the whole to a level surface; and, as the point, or line, along which any bed is cut across, will constitute its new line of outcrop, it follows that the outcrop of the strata cannot correspond upon the two sides of the fault.

REPETITION OF STRATA BY FAULTS.—When faults run at right angles to the *dip*, or coincide more or less nearly with

the *strike* of the beds, there is a repetition of the strata; so that the same beds may follow one another, perhaps several times over, in any given district. This is shown in Figs. 36 and 40, where it is seen that the repeated beds all dip in the

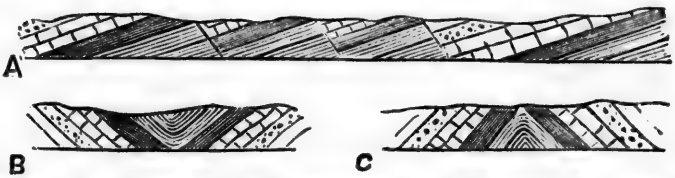


FIG. 40.—A, Strata repeated with the same dip by parallel faults; B, Strata repeated by a synclinal curve; C, Strata repeated by an anticlinal curve.

same direction. When this is the case, even though the *amount* of the dip be changed, there need be little hesitation in ascribing the repetition to faults. If, on the other hand, the repeated beds dip away from one another, then the repetition is probably due to an anticlinal fold (Fig. 40, C); while, if the repeated beds dip toward one another, a synclinal curve is probably present (Fig. 40, B).

CHAPTER XIV.

ON THE RELATIVE AGES OF THE AQUEOUS ROCKS.

We have seen that the series of the stratified or aqueous rocks is composed of a succession of deposits of different ages, and we come now to the question as to how these ages may be determined, and a true succession of the stratified formations established. In solving this question as to the method of determining the age of any particular bed or set of beds, we find that there are three principal tests which may be employed: 1. Superposition; 2. Mineral composition; 3. Included organic remains.

I. Superposition.—The first and most obvious test of the age of any aqueous rock is, its relative position. Any bed, or set of beds, of sedimentary origin, is obviously and necessarily younger than all the beds upon which it rests, and older than all those which surmount it. When the beds are horizontal, there is little difficulty in making out the position of any one of them; but, if the beds are inclined, and especially if they are much folded or faulted, it is often impossible to determine the relative position of any group of beds. Necessarily, too, the order of superposition can only be applied to a limited set of beds, and through limited thicknesses. Lastly, at its best, superposition can only tell us the *relative* and not the *absolute* age of any bed or set of beds. It will tell us with certainty that this or that bed is older or younger than some other bed, but it cannot of itself tell us *how much* older or younger.

If, for example, we find, in one district, rocks of the coal-formation resting upon Silurian strata, we know from the order of succession that the latter are the oldest; but we do not know how much older. The coal-measures might, for all we can tell, be the formation which immediately followed the Silurian rocks, or they might be separated by an enormous in-

terval of time. In practice we can only determine this by an appeal to the order of succession in other regions, and by means of the fossil remains in each set of beds. From the first, we should learn that the coal-formation is never conformable to the Silurian rocks, and that between the two there really intervenes the great formation of the Old Red Sandstone; while the second would show us such a complete difference in the *life* of the two periods, that a great period of time would have to be allowed for on this ground alone.

II. Mineral Characters.—The second test of the age of the aqueous rocks—that of mineral composition—is an extremely unreliable one, and can only be applied to a very limited extent. It is true that great masses of chalk might be taken as tolerably good evidence that we were about the horizon of the Upper Cretaceous rocks; extensive beds of workable coal would afford a fair presumption that our horizon would be that of the Carboniferous rocks; well-developed magnesian limestones would lead us to infer that we had to do with beds of Permian age; and red sandstones, with gypseous clays and rock-salt, would be a strong proof that we were working in the Triassic formation. It is true, also, that if in any unknown region we found the rocks very much cleaved and indurated, consisting mostly of slates and grits, we should have grounds for believing that we were dealing with Silurian or Cambrian rocks; while if they consisted chiefly of more or less incoherent sands, clays, and gravels, we should be equally justified in supposing that we were dealing with rocks of the Tertiary or Post-tertiary period.

Still, in all these cases, and in many other similar ones, we might and sometimes should be wrong. The Cretaceous system of rocks sometimes contains no chalk; workable seams of coal occur in several formations younger than the true coal-formation; magnesian limestone is not exclusively Permian; and red marls and sandstones occur in the Tertiary series. Again, perfectly cleaved and indurated beds occur in some very modern formations; while some of the older rocks are as little hardened and consolidated as most of the Tertiary strata. The test by mineral characters is, therefore, never absolutely conclusive as to the age of any given bed or group of beds. Still, there is no question but that each of the great formations is in a general way characterized in any given country by the occurrence of particular kinds of rocks; and when this evidence is combined with what we learn from fossils, and from the superposition of the rocks, we can arrive at

reliable conclusions as to the age of the beds in any particular region. In one case, also, this test will afford decisive evidence of the *relative* age of two sets of beds; namely, when we find one group of beds containing fragments of another group, in which case the former is, of course, the youngest.

III. Included Organic Remains.—The last test, as to the age of any bed or group of beds, is the nature of the organic remains or "fossils" which occur in it. As in the case of mineral composition, however, this test is neither always applicable, nor in all cases absolutely conclusive. Many aqueous rocks exhibit no traces of life, or are "unfossiliferous," for a thickness of many thousands of feet; and even among fossiliferous rocks many strata occur, of a few feet or yards in thickness, which are wholly without organic remains. Even when fossils do occur, it may not be always possible to decide as to the age of the beds. Many fossils range vertically through several groups of strata, and in some cases even through several formations; and these, therefore, taken by themselves, would not be conclusive evidence as to the age of any particular set of beds.

As the result, however, of a vast number of observations, it is now absolutely certain that the entire stratified series may be divided into a number of groups or formations, each of which is characterized by the occurrence, not of any particular fossil, but of an *assemblage* of fossils peculiar to that formation, and not occurring in company in any other formation. Such an assemblage of fossils, characteristic of any formation, represents the *life* of the period during which that formation was deposited. It follows from this, that whenever we can obtain a series or collection of fossils from any particular bed or set of beds, there is rarely any difficulty in determining precisely the geological horizon of the rock in which the fossils occur.

With certain limitations, we may go much further than this. Not only are the great formations characterized by special and peculiar assemblages of animals or plants; but in a general way each subdivision of each formation has its own characteristic fossils, by which it may be recognized by a competent observer. For instance, whenever we find the singular fossils known as *Graptolites*, we may be certain that we are dealing with Silurian strata (with one or two unimportant exceptions). Not only so; but, if the Graptolites belong to certain genera, we may be sure we are working in *Lower* Silurian beds; and, if certain species are present, we may even be able

to fix upon the exact part or subdivision of the Lower Silurian rocks with which we are occupied. But all this would have to be done under a reservation. Graptolites *might* at any time be found in strata much younger or older than the Silurian rocks. In the same way, the species which we now regard as characteristic of the *Lower* Silurians might at any time be found to have survived into the *Upper* Silurian period. So that we should never forget that, in determining the age of a rock by fossil evidence alone, we are reasoning upon generalizations which are the result of experience, and which may at any time be overthrown by fresh discoveries.

As many allusions will necessarily have to be made to the fossils characteristic of the different formations, it may be as well to give here in a very brief form a synoptical view of the animal and vegetable kingdoms, with more especial reference to the geological aspect of the subject. It may be premised that though most fossil animals and plants are *extinct*, and are not found at the present day upon the globe, nevertheless no fossil is known which may not be referred to one or other of the primary divisions of the animal and vegetable kingdoms. It is chiefly of importance, therefore, that the student should obtain a clear idea of the characters of these great sections.

The animal kingdom is divided into six primary divisions or *sub-kingdoms*, as follows, beginning with the lowest:

I. Protozoa (Gr. *protos*, first; *zoa*, animals). The animals belonging to this section are mostly very minute in point of size, have the body composed

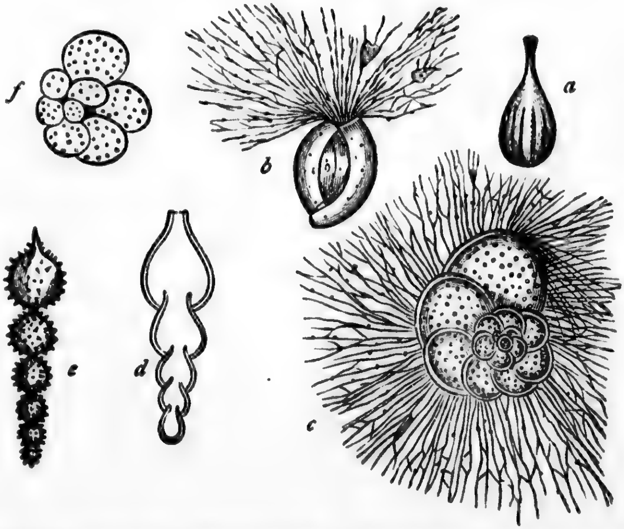


Fig. 41.—Foraminifera (magnified).—*b* and *c* show the shell in its living state; but *a*, *e*, and *f*, merely exhibit the shell.

of a structureless, jelly-like substance, have no nervous system, only rarely possess a mouth, and never possess any distinct digestive cavity or stomach. Most of the *Protozoa* live in the sea or in fresh water, and they are generally not provided with any hard structures, so that they cannot be preserved in a fossil condition. The most important, from a geological point of view, are the *Foraminifera* (Fig. 41) and the Sponges. The former are mostly very small, and have the body protected by a little case of lime or sand, which is often of great beauty. They are found in many rocks, but are especially abundant in the chalk and in some Tertiary strata. The Sponges are well known by the horny sponges of commerce, but the fossil forms possess a skeleton of lime or flint. They are found from the base of the Silurian rocks upward, but are especially abundant in parts of the Cretaceous system.

II. Cœlenterata (Gr. *koilos*, hollow; *enteron*, the intestine). This sub-kingdom includes most of the animals formerly called *Radiates*, and popularly known as "zoophytes," such as sea-firs, sea-anemones, corals, and sea-jellies. They are characterized by the fact that the alimentary canal opens directly into the general cavity of the body. There are rarely any traces of a nervous system; and there is generally a distinct starlike or *radiated* arrangement both of their external parts and internal organs. The most important members of this order are the sea-firs and the corals (Fig. 42). The sea-firs are branched, horny, plant-like organisms, which are composed of numerous minute creatures living associated in colonies. They inhabit the sea, and are believed to be very nearly related to the large and important extinct group of fossils known as *Graptolites*. The corals are much more important, and are represented by numerous fossil forms, occurring in almost all the great geological formations. As before explained (p. 44), corals may be

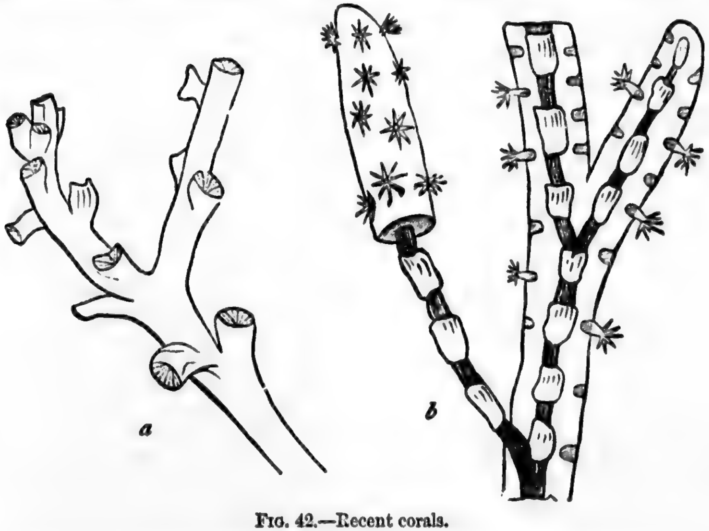


Fig. 42.—Recent corals.

looked upon as essentially sea-anemones, with the power of secreting a hard support or skeleton composed of lime. These skeletons are the parts preserved in a fossil condition; and many limestones are to so great an extent

composed of corals, that we are led to suppose that they must have been ancient coral-reefs. Many fossil corals, however, differ in some important respects from all known living forms.

III. Annuloida (Lat. *annulus*, a ring; Gr. *eidos*, form). The only members of this sub-kingdom which are ever preserved in a fossil condition are the sea-urchins, star-fishes, stone-lilies, and their allies, which together form the class *Echinodermata* (Gr. *echinos*, a hedgehog; *derma*, skin). The name of the class is derived from the generally prickly nature of the skin, due to the power which they all possess, in different degrees, of secreting carbonate of lime in the integument. When fully grown they all exhibit a more or less distinct star-shaped or radiate arrangement of their parts (Fig. 43). The alimentary canal never communicates with the body-cavity, and there is always a well-developed nervous system. Lastly, they all possess a peculiar system of tubes to which water is generally admitted from the exterior, and which is usually concerned in locomotion.

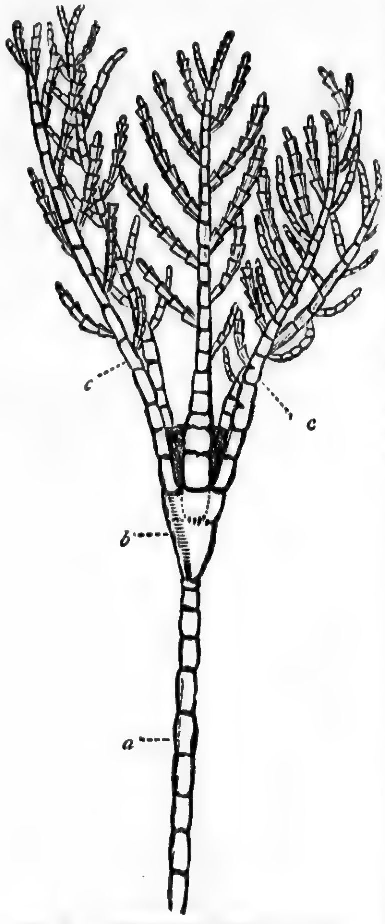


Fig. 43.—*Rhizocrinus Lofotensis*, a living Crinoid (after Wyville Thomson).

The most important members of this group geologically are the stone-lilies (*Crinoids*), the star-fishes and brittle-stars (*Asteroids*), and the sea-urchins (*Echinoids*). The *Crinoids* (Fig. 43) are distinguished by being fixed to the bottom of the sea by a jointed calcareous column or stem, which supports a body not unlike that of a brittle-star. In some cases, only the young is so fixed, and the adult loses its stalk and becomes free. The stone-lilies are very abundant as fossils, and often whole beds are composed of their broken stems. They abounded chiefly in the older periods of the earth's history, and gradually dwindled down, till, at the present day, there are no more than three or four living types of the order. The star-fishes and brittle-stars are well known for their completely starlike form. They occur as fossils in many formations, especially in the Secondary rocks; but they are not of great importance. The sea-urchins are distinguished by their globular, heart-shaped, conical, or cake-like form, and by having the body (Fig. 44) encased in an immovable shell, composed of numerous calcareous plates firmly jointed together. The whole shell is covered with numerous tubercles, which support longer or shorter

movable spines. The Sea-urchins occur as fossils in many formations, but are chiefly found in the Oolitic and Cretaceous rocks.

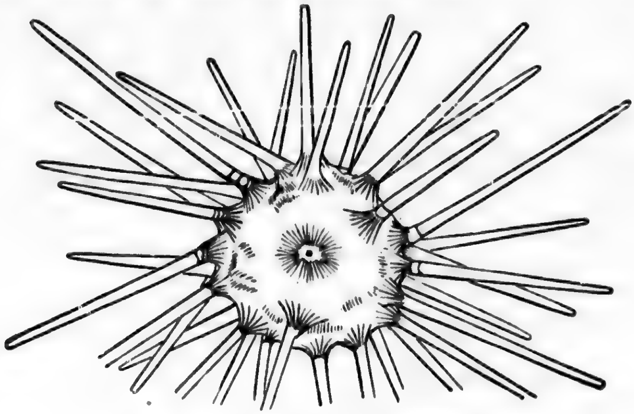


FIG. 44.—A living Sea-urchin (*Cidaris*).

IV. ANNULOSA (Lat. *annulus*, a ring). The members of this sub-kingdom, such as worms, crustaceans, spiders, centipedes, and insects, have a body composed of a number of rings arranged longitudinally one behind the other. There is a distinct alimentary canal, generally circulatory organs, and always a nervous system. The nervous system consists, typically, of two nervous cords placed along the lower surface of the body, and having two little nervous masses developed in each ring. The sub-kingdom is divided into two great divisions, according as the body is furnished with jointed limbs or not. In the former section are the Leeches, Earthworms, Sea-worms, etc., none of which are geologically important, though the Tube-worms not uncommonly occur as fossils. The second section comprises the Crustaceans, Spiders and Scorpions, Centipedes, and Insects, all having jointed appendages articulated to the body; hence the name of *Articulated Animals*, often applied to this section.

The *Crustaceans* comprise the Lobsters, Shrimps, Crabs, Wood-lice, Horse-shoe Crabs, Water-fleas, Barnacles, and Acorn-shells, etc., and are all more or less truly aquatic. They almost always have breathing-organs in the form of *gills;* they have two pairs of feelers; the limbs are usually more than eight in number; and the body is generally protected by a hard shell or "crust" (Fig. 45). The most important extinct groups of the *Crustacea* are the *Trilobites* and *Eurypterids*, both characteristic of the older strata of the earth's crust; but all the forms mentioned above are represented by fossil examples.

The Spiders and Scorpions (*Arachnida*) are terrestrial, and have breathing-organs, adapted for respiring air directly; they have no feelers, as such; and they have four pairs of legs. They occur in a fossil condition, but are rare, and comparatively unimportant.

The Centipedes (*Myriapoda*) have breathing-organs, adapted for respiring air, have one pair of feelers, and have numerous pairs of legs (never less than nine pairs). They rarely are found as fossils, and require no further notice here.

The true Insects (*Insecta*) breathe air directly, have one pair of feelers, and three pairs of legs, generally with one or two pairs of wings. Though not of common occurrence as fossils, insects are of considerable importance from a geological point of view. They have been found in all formations, from the Old Red Sandstone upward.

V. Mollusca (Lat. *mollis*, soft). The Mollusks, or true Shell-fish, have soft bodies, usually protected by a calcareous shell, of one, two, or more pieces. There is a distinct alimentary canal, and generally a heart and circulatory system. The nervous system consists of three scattered masses, united to one another by nervous cords. There may be no respiratory organs, or there are distinct breathing-organs, adapted for breathing air directly, or more commonly through the medium of water. The most important members of the *Mollusca*, from a geological point of view, are the Lamp-shells and their allies, the Bivalves, the Univalves, and the Cephalopods.

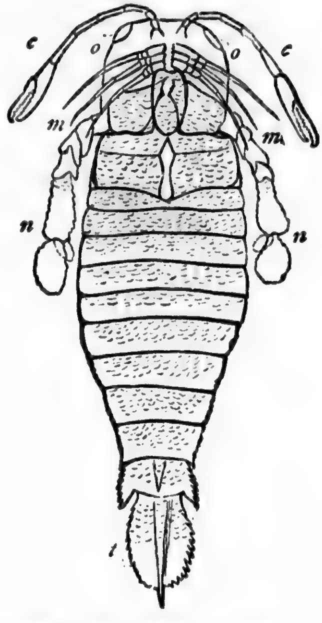


Fig. 45.—Eurypterida.—*Pterygotus Anglicus*, restored (after H. Woodward).

Fig. 46.—Brachiopoda.—*Lingula*, showing the muscular stalk by which the shell is attached.

The Lamp-shells and their allies form the class *Brachiopoda* (Gr. *brachion*, an arm; *podes*, feet), so called because the mouth is furnished with two long, fringed processes or "arms." The body is protected by a "bivalve" shell, composed of two pieces or valves (Fig. 46), which generally differ in size and in other characters as well. They are often placed with the true Bivalve Shell-fish, but their general organization is much lower. The *Brachiopods* are of great geological importance, occurring in all formations after the

earliest, and often in very great abundance. They are an example of a group which has long been on the decline, the living species falling far short of one hundred, while nearly two thousand fossil forms are known.

The Bivalve Mollusks form the class *Lamellibranchiata* (Lat. *lamella*, a thin plate; Gr. *bragchia*, gill), so called from their leaf-like gills. They have a shell composed of two pieces or "valves," which are usually identical in size and shape. Good examples are the Oyster, Mussel, and Scallop. Numerous fossil forms of this class are found in all formations after the oldest.

The Univalve Mollusks are known as *Gasteropoda* (Gr. *gaster*, belly; *podes*, feet), from their creeping about upon a flattened disk formed of the lower surface of the body. Some of them, such as the Slugs, have no visible shell; but most of them have a shell, which is almost always composed of a single piece or "valve" (Fig. 47). The shell varies a good deal in shape, but is mostly coiled into a spiral, as is seen in the common Periwinkles and

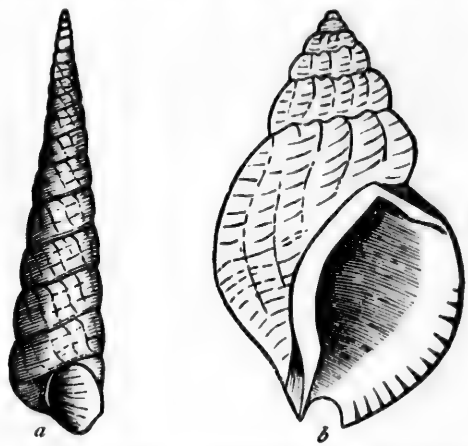


Fig. 47.—Shells of *Gasteropoda.*—*a*, Holostomatous shell (*Turritella communis*); *b*, Siphonostomatous shell (*Buccinum undatum*).

Whelks. The *Gasteropoda* have a great antiquity, and are found, more or less abundantly, in all the great geological formations after the first.

The class *Cephalopoda* (Gr. *kephale*, head; *podes*, feet) comprises the Cuttle-fish and Pearly Nautilus, with a host of fossil forms. They derive their name from the fact that the head is surrounded by a series of "arms" or long processes, which are usually provided with suckers, and by which the animal walks about, head-downward, at the bottom of the sea. The Cuttle-fishes have no external shell, but generally possess a calcareous or horny internal skeleton. The most important fossils referable to this section of the *Cephalopoda* are the singular *Belemnites*, so characteristic of the secondary period of geology. The Pearly Nautilus (Fig. 48) and its fossil allies have a well-developed external shell, which is always divided into a series of chambers by shelly partitions. The animal lives in the last chamber only of the shell, and the partitions of the shell are always pierced by an aperture for the conduction of a peculiar tube known as the "siphuncle."

In the Nautilus and its nearest allies the partitions of the shell are simply curved, and the "siphuncle" is central, or nearly so. In the large and important extinct group of the *Ammonites* the partitions of the shell are

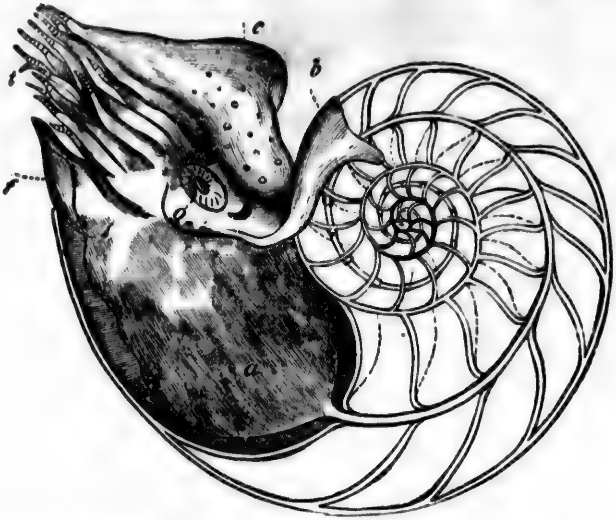


FIG. 48.—Pearly Nautilus (*Nautilus pompilius*).—*a*, Mantle; *o*, Eye; *t*, Tentacles; *f*, Funnel.

wonderfully folded and lobed, instead of being simply curved, and the "siphuncle" is placed on the back of the shell. The Nautilus and its allies occur in all the great formations, but the true Ammonites, with a great number of related forms, are characteristic of the Secondary rocks.

VI. VERTEBRATA (Lat. *vertebra*, one of the bones of the spine or backbone). The Vertebrates are characterized by the almost universal possession of a spinal column or backbone (Fig. 49), composed of numerous bones placed one behind the other, and enclosing the spinal cord. The skeleton is *internal*, and the muscles are attached to its several parts. The limbs may be wanting, or partially undeveloped, but they are always jointed to the body, when present, and there are never more than two pairs. The *Vertebrates* are divided into the following five great classes:

1. *Pisces* (Fishes), distinguished by having gills, and by having the limbs (when present) in the form of *fins*. The heart is mostly two-chambered. The most important groups of Fishes are the Bony Fishes, such as the Salmon, Cod, Herring, etc.; the Ganoid Fishes, such as the Sturgeon and Bony Pike; and the Sharks and Rays. The Bony Fishes are distinguished by their thin, horny scales, their bony skeleton, and symmetrically-lobed tail. The Ganoid Fishes have bony scales covered with enamel, the skeleton usually more or less gristly, and the tail sometimes symmetrical, sometimes unsymmetrical. The Sharks and Rays have scales in the form of detached bony grains or plates, a gristly skeleton, and an unsymmetrically-lobed tail.

2. *Amphibia* (Frogs, Newts, etc.), distinguished by having gills when young, and lungs when fully grown, the gills sometimes remaining through-

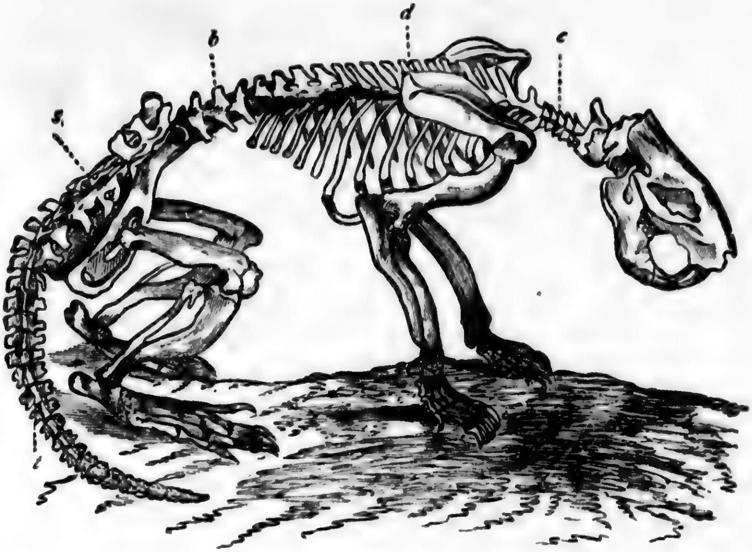


FIG. 49.—Skeleton of the Beaver, showing the regions of the vertebral column.—*c*, *Cervical region*, or neck; *d*, *Dorsal region*, or region of the back; *b*, *Lumbar region*, or region of the loins; *s*, *Sacrum*; *t*, *Caudal region*, or region of the tail.

out life. The limbs may be wanting, but are never in the form of fins. The skull is jointed to the backbone by two articulating surfaces or "condyles." The most important fossil amphibians are the great Labyrinthodonts of the Carboniferous and Triassic periods.

3. *Reptilia* (Reptiles), distinguished by never possessing gills, by having the skin furnished with horny scales or bony plates, and by having the skull jointed to the backbone by one articulating surface or "condyle." The blood is cold, and the heart is almost always three-chambered. The following living orders are included in this class:

a. *Chelonia* (Tortoises and Turtles).
b. *Lacertilia* (Lizards).
c. *Ophidia* (Snakes and Serpents).
d. *Crocodilia* (Crocodiles and Alligators).

All these living orders are represented by extinct forms; but besides these there are five wholly extinct orders, some of them of very remarkable character, belonging to the Secondary period of Geology. The more remarkable of these forms will be noticed in speaking of the rocks in which they occur.

4. *Aves* (Birds), characterized by never possessing gills, by having a covering of feathers, and by having the skull jointed to the vertebral column by a single joint or "condyle." The blood is warm, and the heart is four-chambered. The fore-limbs are generally so modified as to form "wings." The class of Birds is of no high geological antiquity, the earliest example being from the Secondary rocks (Oolites). The class is divided into the following orders:

a. *Natatores* or *Swimming Birds. Ex.*—Ducks, Gulls, Pelicans.
b. *Grallatores* or *Wading Birds. Ex.*—Herons, Storks, Woodcocks.
c. *Cursores* or *Running Birds. Ex.*—Ostrich, Emeu.
d. *Rasores* or *Scratching Birds. Ex.*—Fowls, Game-birds, Pigeons.
e. *Scansores* or *Climbing Birds. Ex.*—Parrots, Woodpeckers.
f. *Insessores* or *Perching Birds. Ex.*—Finches, Larks, Crows.
g. *Raptores* or *Birds of Prey. Ex.*—Hawks, Eagles, Owls.
h. *Saururæ* or *Lizard-tailed Birds*, comprising only the extinct *Archæopteryx* of the Oolitic Rocks.

5. *Mammalia* (Mammals); distinguished by having some part or other of the skin provided with hairs, by having the skull jointed to the backbone by two joints or "condyles," and by never having gills. The blood is warm, and the heart is four-chambered. The young are nourished for a longer or shorter time by means of a special fluid—the milk—secreted by special organs, the mammary glands. The class includes all the ordinary quadrupeds, and is divided into the following orders:

a. *Monotremata. Ex.*—Duck-mole, and Spiny Ant-eater.
b. *Marsupialia. Ex.*—Kangaroos and Opossums.
c. *Edentata. Ex.*—Sloths, Armadillos, Ant-eaters.
d. *Sirenia. Ex.*—Dugong, Manatee.
e. *Cetacea. Ex.*—Whales and Dolphins.
f. *Ungulata* (Hoofed Quadrupeds). *Ex.*—Rhinoceros, Hippopotamus, Pigs, Tapirs, Giraffe, Deer, Antelopes, Sheep, Goats, Oxen.
g. *Hyracoidea. Ex.*—*Hyrax.*
h. *Proboscidea. Ex.*—Elephant.
i. *Carnivora. Ex.*—Seals, Walrus, Bears, Raccoons, Dogs, Wolves, Hyænas, Lions, Tigers.
j. *Rodentia. Ex.*—Mouse, Rat, Beaver, Squirrel.
k. *Cheiroptera. Ex.*—Bats.
l. *Insectivora. Ex.*—Moles, Shrew-mice, Hedgehogs.
m. *Quadrumana. Ex.*—Lemurs, Baboons, Apes.
n. *Bimana.*—Man.

VEGETABLE KINGDOM.

The following are the main subdivisions of the Vegetable Kingdom:

I. Cryptogamic Plants (Gr. *kruptos*, concealed; *gamos*, marriage), distinguished by having no distinct flowers or fruit. They include:

a. *Thallogens. Ex.*—Sea-weeds (*Algæ*), Lichens, Mushrooms.
b. *Anogens. Ex.*—Liverworts, Mosses.
c. *Acrogens. Ex.* — Club-mosses (*Lycopodiaceæ*), Ferns, Horse-tails (*Equisetaceæ*).

II. Phanerogamic Plants (Gr. *phaneros*, conspicuous; *gamos*, marriage); distinguished by having distinct flowers and seeds. They are divided into:

a. *Endogens. Ex.*—Grasses, Palms, Lilies. These have *endogenous* stems, showing no rings of growth, and the young plant possesses but a single seed-lobe or "cotyledon." Hence they are often called *Monocotyledons.*

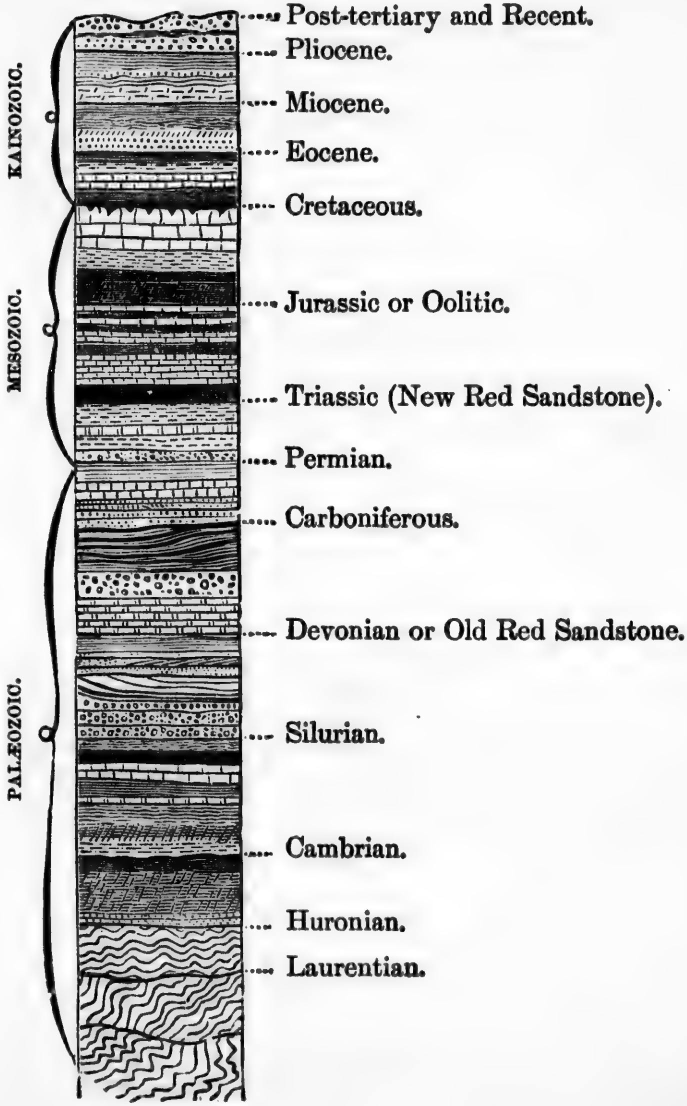
b. *Exogens. Ex.*—Pines and Cycads, with most ordinary shrubs, trees, and flowering plants. The Pines and Cycads, with the fossil *Sigillariæ*, have the seed naked, and are hence called *Gymnosperms* (Gr. *gumnos*, naked; *sperma*, seed). Ordinary trees and shrubs, on the other hand, have the seed covered, and are therefore called *Angiosperms.* Both the Gymnosperms and Angiosperms have an *exogencus* mode of growth, with a true bark and annual

rings of growth. The seed also possesses two seed-lobes or "cotyledons;" and they are therefore often spoken of as *Dicotyledons*.

CHRONOLOGICAL SUCCESSION OF THE AQUEOUS ROCKS.—As the result of observations made upon the superposition of rocks in different localities, from their mineral characters, and from their included fossils, geologists have been able to divide the entire stratified series into a number of different divisions or formations, each characterized by a *general* uniformity of mineral composition, and by a special and peculiar *assemblage* of organic forms. Each of these primary groups is in turn divided into a series of smaller divisions, characterized and distinguished in the same way. It is not pretended for a moment that all these primary rock-groups can anywhere be seen surmounting one another regularly. There is no region upon the earth where all the stratified formations can be seen together; and, even when most of them occur in the same country, they can nowhere be seen all succeeding each other in their regular and uninterrupted succession. The reason of this is obvious. There are many places—to take a single example—where one may see the Silurian rocks, the Old Red Sandstone, and the Carboniferous rocks succeeding one another regularly, and in their proper order. This is because the particular region where this occurs was always submerged beneath the sea while these formations were being deposited. There are, however, many more localities in which one would find the Carboniferous rocks resting unconformably upon the Silurians without the intervention of any strata which could be referred to the Old Red Sandstone. This might arise from one of two causes: 1. The Silurians might have been elevated above the sea immediately after their deposition, so as to form dry land during the whole of the Old Red period, in which case, of course, no strata of the age of the Old Red Sandstone could possibly be deposited. 2. The Old Red Sandstone might have been deposited upon the Silurian, and then the whole might have been elevated above the sea, and subjected to an amount of denudation sufficient to remove the Old Red Sandstone entirely. In this case when the land was again submerged, the Carboniferous rocks, or any younger formation, might be deposited directly upon Silurian strata. From one or other of these causes, then, or from subsequent disturbances and denudations, it happens that we can rarely find many of the primary formations following one another consecutively and in their regular order.

IDEAL SECTION OF THE CRUST OF THE EARTH.

Fig. 50.



The main subdivisions of the Stratified Rocks are known by the following names:

1. Laurentian.
2. Cambrian (with Huronian ?).
3. Silurian.
4. Devonian or Old Red Sandstone.
5. Carboniferous.
6. Permian, } New Red Sandstone.
7. Triassic, }
8. Jurassic or Oolitic.
9. Cretaceous.
10. Eocene.
11. Miocene.
12. Pliocene.
13. Post-tertiary.

Of these primary groups, the Laurentian, Cambrian, Silurian, Devonian, Carboniferous, and Permian, are collectively grouped together under the name of *Primary* or *Palæozoic* rocks (Gr. *palaios*, ancient; *zoe*, life), because of the entire divergence of their animals and plants from any now existing upon the globe. The Triassic, Jurassic, and Cretaceous systems, are grouped together as the *Secondary* or *Mesozoic* formations (Gr. *mesos*, intermediate; *zoe*, life), because their organic remains are intermediate between those of the Palæozoic period, and those of more modern strata. The Eocene, Miocene, Pliocene, and Post-tertiary rocks, are grouped together under the head of *Tertiary* or *Kainozoic* rocks (Gr. *kainos*, new; *zoe*, life), because their organic remains approximate in character to those now existing upon the globe.

All these separate formations require to be noticed somewhat in detail, and in so doing it is best to begin with the lowest and gradually work our way upward. The foregoing illustration represents an ideal section of the crust of the earth, showing the succession of the great formations (Fig. 50).

CHAPTER XV.

LAURENTIAN, HURONIAN, AND CAMBRIAN GROUPS.

LAURENTIAN SERIES.—The oldest formation with which we are as yet acquainted is that of the *Laurentian* rocks, so called because they are largely developed in Canada, north of the river St. Lawrence. A large area of these rocks also occurs in Northern New York, rising into the lofty and rugged elevations of the Adirondacks, and there is a third area to the south of Lake Superior. The Laurentian series is of vast thickness, and is divided into a lower and upper division. The *Lower Laurentian* group attains the enormous thickness of about 20,000 feet, and is composed entirely of metamorphic rocks, consisting mainly of gneiss interstratified with mica-schist, with great beds of quartz, and massive beds of crystalline limestone, of which one varies from 700 to 1,500 feet in thickness. Conglomerates also occur, and there are vast deposits of magnetic and specular iron-ore. Graphite or black-lead—which is merely a form of carbon—occurs disseminated in strings, veins, and beds, through hundreds of feet of Lower Laurentian strata, and its amount is calculated by Dr. Dawson to be equal in quantity to the coal-seams of an equal area of the Carboniferous rocks.

Not only is the Lower Laurentian series of vast thickness and greatly metamorphosed, but it must have been elevated above the sea, and subjected to vast denudation, prior to the deposition of the upper group. This is shown by the fact that the Upper Laurentian lies unconformably upon the truncated edges of the Lower Laurentian. The *Upper Laurentian* group is about 10,000 feet thick, and consists wholly of stratified crystalline rocks. These consist mainly of gneissic and felspathic rocks, often characterized by the occurrence of lime-felspar or Labradorite. The series is extensively devel-

oped in Labrador, and is sometimes spoken of as the "Labrador Series."

European Laurentian Rocks. — As regards the occurrence of Laurentian rocks in Britain, there is still some uncertainty. In the Hebrides and along the western shores of Sutherlandshire (Scotland) Sir Roderick Murchison showed that there occurred great masses of highly-crystalline gneiss (Fig. 51, *a*). Upon the truncated and highly-inclined beds of this

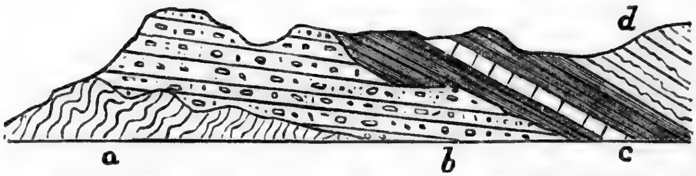


Fig. 51.—Diagrammatic section of the old rocks of the Northern Highlands of Scotland, after Sir R. Murchison.—*a*, Laurentian (?) gneiss; *b*, Red sandstones and conglomerates of Cambrian (?) age; *c*, Lower Silurian quartz-rock and fossiliferous limestone; *d*, Metamorphosed Lower Silurian strata.

"fundamental gneiss" lie great beds of red sandstone and conglomerate (*b*); and these are in turn succeeded unconformably by quartz-rock and interstratified limestone (*c*). These last contain Lower Silurian fossils; so that the red sandstones and conglomerates beneath them must almost certainly be Cambrian. The lowest gneiss is, however, in a doubtful position. It is believed by Sir R. Murchison to be Laurentian, but it may, perhaps, be Huronian. There are some other British rocks which are believed to be referable to the Laurentian series; and it is highly probable that Laurentian rocks will hereafter be shown to exist in other parts of Europe.

Life of the Laurentian Period.—The Laurentian rocks are often spoken of as the *Azoic series* (Gr. *a*, without; *zoe*, life); but the name appears to be inappropriate, because there is good evidence to show that living beings were in existence in the Laurentian period. In the first place, it is certain that the Laurentian rocks, though now highly metamorphic, were originally deposited as ordinary sedimentary beds of sandstone, conglomerate, shale, and limestone. There is, therefore, no reason whatever for supposing that the seas of the Laurentian period differed in any respect from modern seas, so far at any rate as to render the occurrence of living beings impossible; while we know that one of the results of metamorphic action is the obliteration of the fossils in the rock affected. Secondly,

by the researches of Sir William Logan there was discovered in one of the limestones of the Lower Laurentian group a body which has been described under the name of *Eozoön Canadense*, and is believed to be a gigantic *Foraminifer*. The organic nature of this body was first detected by Dr. Dawson, of Montreal, and his opinion as to its nature has since been confirmed by the highest authorities. Thirdly, there is good reason to believe that the graphite of the Laurentian rocks is nothing more than metamorphic *coal*, and that it is derived from vegetables which flourished during the Laurentian period.

Huronian Series.—Resting unconformably upon the denuded edges of the Laurentian rocks on the borders of Lakes Superior and Huron, is another great series of metamorphic rocks, to which the name of *Huronian* has been applied by Sir William Logan. They are about 18,000 feet in thickness, and consist of quartzites (altered sandstones), siliceous slates, conglomerates, and limestones. The conglomerates sometimes contain pebbles derived from the subjacent Laurentian rocks. No fossils have hitherto been found in any part of the Huronian series, and its exact age is, therefore, doubtful. Not improbably it may correspond with the Lower Cambrian rocks of other regions, but it may represent an independent formation to be intercalated in point of time between the Laurentian and Cambrian groups.

Cambrian Series.—The exact limits of the *Cambrian rocks* are as yet not well defined, different authorities taking different views as to the strata which should be considered under this head. The name "Cambrian" is derived from the fact that these strata are the lowest rocks visible in North Wales and its borders (Cambria). The Cambrian rocks are generally divided into a Lower and Upper division, and they are well developed in various parts of Europe and America. The following gives a general idea of the nature, distribution, and mineral characters of the Cambrian rocks:

I. *Cambrian Rocks of Britain.*—The *Lower Cambrian* rocks of Britain are best seen in the Longmynd Hills in Shropshire, and consist of about 25,000 feet of variously-colored sandstones, grits, and shales, often ripple-marked, and exhibiting rain-prints, but with very few fossils. These are succeeded by a great series of micaceous flagstones, slates, and shales, which vary in thickness from 6,000 to 2,000 feet, and are of *Upper Cambrian* age. They are known as the *Lingula Flags*, from the occurrence in them of a Brachiopod belonging to the genus *Lingula* (Fig. 57). In North Wales the Lower Cambrian strata are often highly metamorphosed, and the celebrated Welsh roofing-slates are also derived from this division. Cam-

brian rocks occur in other parts of Britain, and the following table exhibits their leading members:

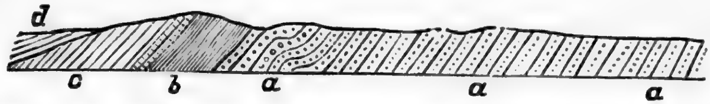


FIG. 52.—Section of the Cambrian rocks of the Longmynd.—*a*, Lower Cambrian grits, sandstones, and shales; *b*, Lingula flags (Upper Cambrian); *c*, Lower Llandeilo rocks (Lower Silurian); *d*, Upper Silurian strata.

1. *Lower Cambrian:*
   a. Longmynd beds (25,000 feet).
   b. Llanberis slates (3,000 feet).
   c. Harlech grits (6,000 feet).
   d. *Oldhamia* slates of Ireland.
2. *Upper Cambrian:*
   e. Lingula Flags of Wales (about 6,000 feet).
   f. Tremadoc slates of North Wales (2,000 feet).
   g. Skiddaw slates of the north of England (7,000 feet).

The last-mentioned group of rocks, namely, the Skiddaw slates of the north of England, are in a doubtful position. They consist of about 7,000 feet of dark-colored shales and slates, and they are most clearly the equivalent of the Quebec group of Canada, containing many of the same fossils. Upon the whole, it seems safer in the mean while to regard them as Upper Cambrian.

II. *Cambrian Rocks of Bohemia and Sweden.*—In Bohemia, M. Barrande has succeeded in demonstrating as underlying the Lower Silurian rocks of that country a zone of rocks, which correspond to the Lingula Flags of Britain, and are, therefore, of Upper Cambrian age. This zone contains many remarkable and characteristic fossils, and is often spoken of as the "Primordial Zone." In Sweden and Norway the Lower Cambrian rocks are represented by a sandstone containing impressions supposed to be referable to sea-weeds or "fucoids." This "Fucoidal sandstone" is succeeded by beds of so-called "alum-schist," which are of Upper Cambrian age, and correspond with the Lingula Flags of Britain. Among the most characteristic of the fossils of this "Primordial Zone" are the singular crustaceans known as *Trilobites*, of which an example is figured on p. 128 (Fig. 53).

III. *Cambrian Rocks of North America.*—The Cambrian rocks are represented in North America by the Potsdam sandstone and the Calciferous series. The *Potsdam sandstone* is mostly a laminated sandstone, or grit, in the State of New York, but limestones are present in addition in the Mississippi basin, and it consists of a great thickness (2,000 to 7,000 feet) of slates, sandstones, and limestones, along the Appalachian chain. It contains a good many fossils, among which are Trilobites resembling those of the "Primordial Zone" in Bohemia. A characteristic form is figured hereafter (Fig. 54).

The *Calciferous* series consists of a hard calcareous sandstone, or "sand-rock," in the State of New York; but it consists of sandstone with well-developed magnesian limestone in the basin of the Mississippi; and along the Appalachian chain it consists of sandstones and limestones, subordinated to great masses of shale. In their last-mentioned development the Calciferous rocks have been termed the "Quebec group," and, as before said, they are

undoubtedly the equivalent of the Skiddaw slates of Britain. They attain a thickness of from 5,000 to 7,000 feet; but it is not clear whether they are truly referable to the Upper Cambrian or to the base of the Silurian system. Most probably they are transition-beds between the two formations.

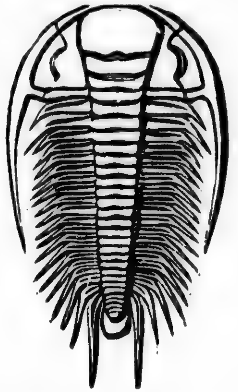


FIG. 53.—*Paradoxides*, a Trilobite from the "Primordial Zone" of Bohemia.

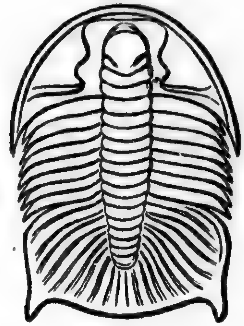


FIG. 54.—*Dikelocephalus Minnesotensis* (Dale Owen); one of the Trilobites of the Potsdam Sandstone.

LIFE OF THE CAMBRIAN PERIOD.—The life of the Cambrian period is but scanty, and the forms represented are all, comparatively speaking, low in the zoological scale. In the Lower Cambrian rocks fossils have hitherto proved extremely scarce. With the exception of one doubtful fossil, the commonest organic remains are the burrows of sea-worms, allied to the common Lob-worm of our coasts. These are very abundant, and are found even among the hardest and most quartzose rocks of the formation. In rocks believed to be of this age in Ireland occurs the singular fossil called *Oldhamia* (Fig. 55), the exact nature of which is uncertain. It is sometimes believed to be most closely allied to the Sea-firs (*Sertularians*); but the more probable view is that it is a calcareous sea-weed, like the "corallines" of the present day.

FIG. 55.—*Oldhamia antiqua* (Forbes).

In the Upper Cambrian rocks, fossils become pretty plentiful, and some higher types appear. Trilobites are especially abundant, and belong to peculiar types in most instances.

Some of the characteristic forms have been already figured (Figs. 53, 54), and one of the species from the Lingula flags is given below (Fig. 58). Besides Trilobites, the Lingula flags contain in abundance the remains of another Crustacean, *Hymenocaris vermicauda* (Fig. 56). The *Lingula* (Fig. 57), from

LINGULA FLAG FOSSILS.

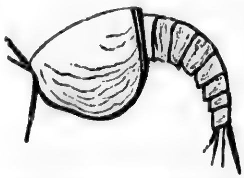


FIG. 56.—*Hymenocaris vermicauda.* ½ nat. size.

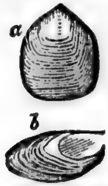


FIG. 57.—*Lingula Davisii.* *a.* ½ nat. size. *b.* Distorted by cleavage.

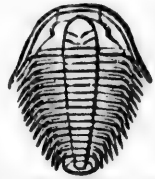


FIG. 58.—*Olenus micrurus.* ½ nat. size.

which the name of this group is derived, is a Brachiopodous shell, and is found in great abundance. In the Primordial Zone of Bohemia, and in the alum-schists of Scandinavia are contained many Trilobites, while the former has also yielded a few Brachiopods and some Echinoderms. The Potsdam Sandstone contains Trilobites, a small Brachiopod, burrows and tracks of sea-worms, and other fossils. In the Upper Cambrian rocks appear for the first time the singular fossils known as *Graptolites* (Gr. *grapho*, I write; *lithos*, stone). These curious organisms are believed to be most nearly allied to the living sea-firs, but they are in many respects quite peculiar and unlike all recent organisms. In the Quebec group of Canada, and in the Skiddaw slates of Britain, *Graptolites* occur in great plenty, and in the most varied forms. One of the most characteristic species is figured below (Fig. 59). In the Skiddaw slates also occur the remains of what must almost certainly be regarded as marine plants of some kind or other. Fossils of an apparently vegetable nature have also been discovered in the Cambrian rocks of Sweden.

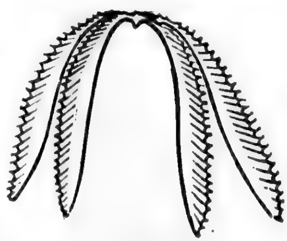


FIG. 59.—*Tetragrapsus bryonoides*, a Skiddaw-slate Graptolite.

Lastly, in the Potsdam Sandstone have been detected the earliest footprints as yet discovered. These have been described under the name of *Protichnites*. They were at first be-

lieved to have been made by some animal of the Turtle family, but they are considered by Owen to be the tracks of some large Crustacean. Their size is very remarkable, as they indicate an animal of probably several feet in length.

TABULAR VIEW OF THE CHIEF CAMBRIAN STRATA.

1. *Lower Cambrian* (= Huronian ?):
   - *a.* Longmynd beds, Llanberis Slates, and Harlech Grits of Britain.
   - *b.* Fucoidal Sandstone of Sweden.
2. *Upper Cambrian:*
   - *c.* Lingula Flags and Tremadoc Slates of Britain.
   - *d.* "Primordial Zone" of Bohemia.
   - *e.* Alum-schists of Sweden.
   - *f.* Potsdam Sandstone and Calciferous Sand-rock of North America.
   - *g.* Quebec Group of Canada (?).
   - *h.* Skiddaw Slates of north of England (?).

CHAPTER XVI.

SILURIAN SERIES.

FOLLOWING the Cambrian comes the great Silurian series of rocks, first clearly established and definitely worked out by Sir Roderick Murchison, the founder of the Silurian system. The exact limit between the Cambrian and Silurian formations is one which is not clearly defined, since there does not appear to be any general physical break between the two groups. The line of demarcation between them is in the present state of our knowledge an arbitrary line, and is derived chiefly from the characters of the *Trilobites*. There are rocks, however, such as the Tremadoc slates, the Skiddaw slates, and the Calciferous and Quebec group, in which there is an intermixture of Cambrian with true Lower Silurian types. These rocks, therefore, might be regarded as Upper Cambrian or as Lower Silurian, or as passage-beds between the two. It is to be remembered, also, that the Tremadoc slates and Lingula flags are regarded by Sir Roderick Murchison as being the basement-beds of the Lower Silurian.

The name "Silurian" was proposed by Sir R. Murchison for a great series of strata lying below the Old Red Sandstone, and occupying those parts of Wales and England which were at one time occupied by the "Silures," a tribe of ancient Britons. The Silurian rocks are largely developed in Wales, the north of England, Scotland, and Ireland, in various parts of Europe, especially Bohemia, Saxony, Russia, and Sweden, and in the North American Continent. The entire series is divisible into the two sections of the Lower and Upper Silurian rocks, each in turn split up into smaller subdivisions, the names of which have usually been taken from localities where they are unusually well developed, or where they were first studied. We shall consider each of these divisions separately, first as

they occur in Britain, and then as they are developed in North America; the former country having been generally adopted by geologists as the typical Silurian region of the world. It is also the region which forms the special subject of Sir Roderick Murchison's classical work "Siluria."

SILURIAN ROCKS OF BRITAIN.—The Silurian rocks of Britain, as indicated in the annexed section, are divided into the following groups from below upward:

a.	Lower Llandeilo group,	Lower Silurian.
b.	Upper Llandeilo group,	
c.	Bala, Caradoc, or Coniston group,	
d.	Lower Llandovery group,	
e.	Upper Llandovery group,	Upper Silurian.
f.	Wenlock group,	
g.	Ludlow group,	

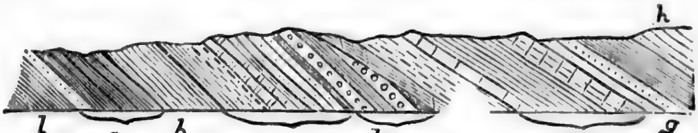


FIG. 60.—Generalized section of the Silurian Rocks of Britain.

1. The *Lower Llandeilo* group (Fig. 60, *a*) derives its name from the town of Llandeilo, in Wales, where it consists of dark-colored micaceous flags, with earthy shales and gritty sandstones. It contains Brachiopods, Trilobites, Graptolites, and other fossils, and one of the most characteristic of the latter is figured below (Fig. 61).

FIG. 61.—Didymograpsus patulus (Hall).—Lower Llandeilo, Quebec, and Skiddaw groups.

2. The *Upper Llandeilo* group consists in Wales of a great series of micaceous flags and dark-colored shales, often with interstratified igneous matter. In Scotland this group consists of a great assemblage of shales and grits, the former mostly very dark in color, with anthracitic lands containing numerous *Graptolites.* Besides these singular organisms, the Upper Llandeilo rocks of Wales contain numerous *Brachiopods*, *Cephalopods*, and *Trilobites.* Two of the most characteristic of the last-mentioned fossils are figured on p. 133 (Figs. 62, 63).

UPPER LLANDEILO FOSSILS.

FIG. 62.—*Asaphus tyrannus.*

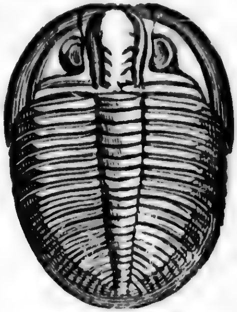


FIG. 63.—*Ogygia Buchii.*

3. The *Bala* or *Coniston* group consists in Wales of slates, grits, and sandstones, to the thickness of about 5,500 feet, with two interstratified limestones. In the north of England it consists of black flags, a well-marked limestone with intercalated shales, and black mudstones containing numerous Graptolites. The group is also well developed in Scotland and Ireland. Wherever it occurs, the Bala formation is richly fossiliferous, its most characteristic fossils being *Brachiopods*, belonging chiefly to the genus *Orthis* (Figs. 64, 65), and having a peculiar, simple, plaited form.

BRACHIOPODS OF THE BALA GROUP.

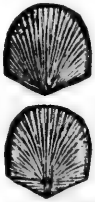


FIG. 64.—*Orthis tricenaria.* ½ nat. size.

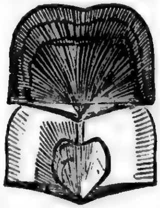


FIG. 65.—*Orthis vespertilio.* ½ nat. size.

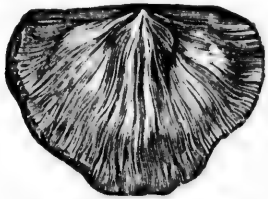


FIG. 66.—*Strophomena grandis.* ⅔ nat. size.

It is also characterized by several *Trilobites*, and by a group of peculiar *Echinoderms*, which are related to the Crinoids or stone-lilies, and which are known as *Cystideans* (see p. 139 Fig. 78).

4. The *Lower Llandovery* group is so called from its oc-

currence near the town of Llandovery, in South Wales. It consists of slates and sandstones, with great beds of conglomerate, and it is unconformably overlaid by the Upper Llandovery group, in which also most of its fossils occur.

5. The *Upper Llandovery* group forms in Britain the base of the Upper Silurians, and rests unconformably upon the Lower Llandovery, which forms the summit of the Lower Silurians. This want of conformity, however, between the Lower and Upper divisions of the Silurian series, though certainly the rule in Britain, does not seem to exist elsewhere. The Upper Llandovery group consists of limestones, shales, conglomerates, sandstones, and slates, and attains a considerable thickness (nearly 2,000 feet). Among its most characteristic fossils, abounding especially in the limestones, are Brachiopods of the genus *Pentamerus* (Fig. 67).

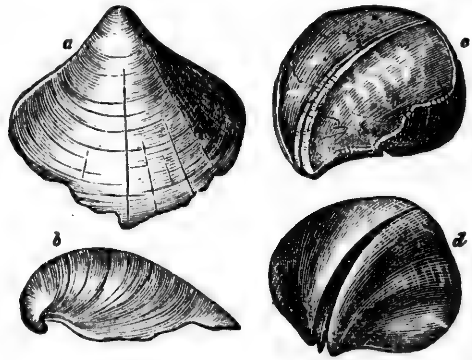


Fig. 67.—*Pentamerus lævis*, a Brachiopod of the Upper and Lower Llandovery groups.

6. The *Wenlock* group consists of a great mass of shale and fla one, underlaid and surmounted by limestones, the whole aining a thickness of 3,000 feet. It is richly charged with fossils, of which, perhaps, the most characteristic are corals (Figs. 68, 69, 70.) Besides these, however, occur numerous *Brachiopods* and *Trilobites*, with various forms of *bivalve* and *univalve Shell-fish*.

7. The *Ludlow* group consists of shales, limestones, and sandstones, in Wales, and of grits and shales in the north of England, having a total thickness of from 2,000 to 4,000 or 5,000 feet or more.

The entire series is charged with very numerous fossils,

Wenlock Corals.

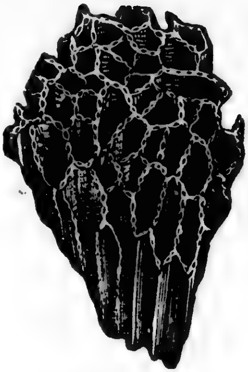


Fig. 68.—*Halysites catenularius*, the "chain coral."

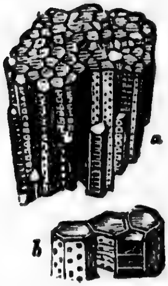


Fig. 69.—*Favosites Gothlandica.*

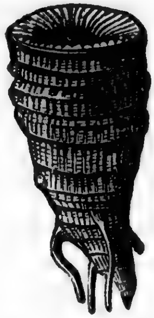


Fig. 70.—*Omphyma turbinatum.*

comprising Sponges, Brachiopods, univalve and bivalve Mollusks, Crinoids and Star-fishes, Trilobites and other *Crustacea*, and a few Graptolites. Some of the more characteristic *Brachiopods* are figured below.

Ludlow Brachiopods.

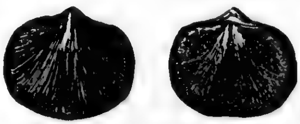


Fig. 71.—*Orthis elegantula.*

Fig. 72.—*Rhynchonella navicula.*

Fig. 73.—*Rhynchonella Wilsoni.*

Besides the above, and more remarkable than any of these, are certain remains of fishes, which present us with the first undoubted traces of vertebrate animals upon the globe. The remains in question are those of fishes belonging to the genus *Pteraspis*, and to the order of the *Ganoid* fishes. The head

was covered with a singular buckler or shield (Fig. 74), and in common with other Ganoids the scales were in the form of bony plates covered by shining enamel. The tail, also, as in most Ganoids, consisted of two unequal or unsymmetrical lobes.

Fig. 74.—Buckler covering the head of *Pteraspis Banksii*, from the Ludlow rocks (after Murchison).

At the very summit of the Upper Ludlow rocks is a well-known stratum, varying from one inch to nearly one foot in thickness, and known as the "bone-bed." In this bed occur the remains of fishes probably most nearly allied to the living Port Jackson shark. Spines of such fishes occur in abundance, and have been referred to the genus *Onchus* (Fig. 75); with these also occurs the shagreen of a shark-like fish, for which the genus *Thelodus* (Fig. 76) has been constituted.

Fishes of the Ludlow Bone-Bed.

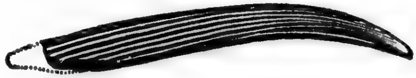


Fig. 75.—*Onchus tenuistriatus.*

Fig. 76.—Shagreen scales of *Thelodus.*

This bed is further of interest as containing the earliest remains of land-plants. These are in the form of numerous minute globular bodies, which have been determined by Dr. Hooker to be the seed-vessels of a cryptogamic land-plant, probably most nearly allied to our club-mosses.

Silurian Rocks of North America.—The Silurian series of North America is a remarkably full and varied one, and a general correspondence can readily be established between it and the British series. The two series, however, differ in certain important points, and nothing more than a general equivalency can be asserted to exist between them. The main divisions of the Silurian rocks of North America are as follows (Fig. 77):

a. Trenton Period, } Lower Silurian.
b. Hudson Period, }
c. Niagara Period, }
d. Salina Period, } Upper Silurian.
e. Lower Helderberg Period, }

1. The *Trenton* period corresponds to the Llandeilo period of Britain, and is characterized by the predominance of limestones, of which the two most important are the Chazy Limestone and the Trenton Limestone. The Trenton Limestone is

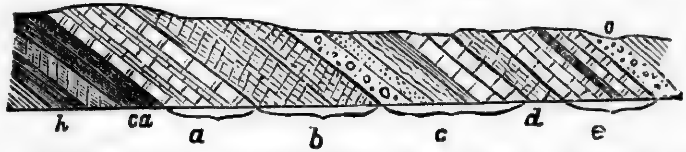


FIG. 77.—Generalized section of the Silurian rocks of North America.—*a*, Limestones of the Trenton period; *b*, Hudson River and Utica slates; *c*, Niagara group; *d*, Salina group; *e*, Lower Helderberg group.

splendidly exposed at the Falls of Trenton in Central New York, and is believed to be higher than the Llandeilo, and to represent the Bala Limestone of Wales. Fossils are extremely abundant in the Trenton period, consisting especially of Brachiopods, Trilobites, and Cephalopods allied to the Nautilus.

2. The *Hudson* period comprises the two groups of the *Utica Shales* and *Hudson River Shales*, both well exhibited in the State of New York. The *Utica Shale* varies in thickness from 15 to 300 feet or more, and consists chiefly of dark-colored shales, sometimes with intercalated beds of limestone. The *Hudson River Shales* vary from 20 to 1,600 feet in thickness, and consist generally of shales or slates, becoming, however, highly calcareous in the West. The shales of both groups are often highly carbonaceous. The fossils are chiefly Trilobites, Corals, and Bivalve Mollusks, with an abundance of Graptolites. The Hudson period is believed to correspond with the Bala or Coniston period of Britain.

3. The *Niagara* period in its fullest development comprises conglomerates and sandstones at the base (Oneida group), marls and sandstones (Medina group), sandstones and shales, sometimes calcareous (Clinton group), and shales and limestones (Niagara group). The fossils are extremely abundant, the predominant forms being Corals, Crinoids, and Brachiopods. The Niagara limestone, over which the Niagara River is precipitated to form the great falls, is undoubtedly the equivalent of the Wenlock group of Britain. The lower beds, namely the Clinton, Medina, and Oneida groups, probably correspond with the Llandovery groups of Wales.

4. The *Salina* period comprises marls, sandstones, and limestones, with masses of gypsum, the whole impregnated in

many places with salt. The salt is obtained for commercial purposes from wells sunk in the strata to a depth of sometimes more than 300 feet, the brine thus obtained being subsequently evaporated by the heat of the sun, or artificially. Fossils are very scarce in this period.

5. The *Lower Helderberg* period derives its name from the Helderberg Mountains, south of Albany, where the rocks of this period attain a thickness of more than 200 feet. The Lower Helderberg strata are essentially limestones, capable of being subdivided in the State of New York into several minor subdivisions, characterized by their included organic remains or mineral characters. The fossils of the period are extremely abundant and consist chiefly of Corals, Crinoids, and Brachiopods, among which last the genus *Pentamerus* (Fig. 67) is conspicuously represented. The Lower Helderberg period is believed to correspond with the Ludlow period in Britain.

The annexed table shows the subdivisions of the Silurian series as developed in the State of New York, and their supposed British equivalents; the table being in ascending order:

Silurian strata of New York.	*British equivalents.*
1. Trenton period (comprising the Chazy, Birds-eye, Black-River, and Trenton limestones). 2. Hudson period (comprising the Utica shales and Hudson River shales).	The Lower Silurian series (comprising the Llandeilo, Bala, and Lower Llandovery groups).
3. Niagara period (comprising the Oneida conglomerate, Medina sandstone, Clinton group, and Niagara limestone).	The lower portion of the Upper Silurian series (comprising the Upper Llandovery and Wenlock).
4. Salina period (comprising the Guelph limestone and Onondaga salt group).	No British equivalent.
5. The Lower Helderberg period (comprising the Tentaculite and Water-lime groups, the Lower Pentamerus limestone, the Delthyris shaly limestone, and the Upper Pentamerus limestone).	The higher portion of the Upper Silurian series (comprising the Ludlow group).

Life of the Silurian Period.—In the lower portion of the Cambrian series, as we have seen, organic remains are exceedingly scanty; but in the upper portion of the same fossils are tolerably abundant, and belong in part to types which pass upward into the overlying Silurian series. The fossils of the Silurian series are almost exclusively marine, the only exception being the traces of land-plants allied to recent Club-mosses which have been discovered in the very highest beds of the system. The only other vegetable remains which have been hitherto detected are referable to sea-weeds, and these are tolerably plentiful and well preserved in some beds. The

lower forms of animal life (*Protozoa*) are represented by Foraminiferous Shells and by Sponges, as well as by certain singular fossils which are apparently transition-forms between the two. The Zoophytes (*Cœlenterata*) are represented by the *Graptolites*, and by numerous Corals. The former are almost exclusively Silurian fossils, and are preëminently characteristic of the *Lower* Silurian rocks. They commence in the Upper Cambrians, in which they seem to attain their maximum (supposing the Skiddaw and Quebec groups to be rightly referred to this formation). They are represented by many forms in the Lower Silurians, and they are found in greatly-diminished numbers in the Upper Silurian rocks, only a single genus being known to have survived into the succeeding period of the Old Red Sandstone. Corals are very abundant in many parts of the Silurian series, certain formations, such as the Niagara limestone, being so largely composed of these fossils, that they have been supposed to be ancient coral-reefs. The *Echinoderms* are more especially represented by the group of the *Crinoids*, or Stone-lilies, of which many beautiful forms occur in both Lower and Upper Silurian strata. Nearly allied to the Crinoids is a singular group of Echinoderms known as *Cystideans* (Fig. 78), which are preëminently characteristic of the Lower Silurian period, but are found in diminished numbers in the Upper Silurians. They resembled the Crinoids in having a jointed stalk or column, which in most cases served as a stem of attachment; but the body was protected by calcareous plates immovably jointed together, and there were rarely any true arms. The groups of the Star-fishes and Brittle-stars were also found in Silurian seas, and are especially abundant in the Upper Silurian period; but no true Sea-urchins have hitherto been discovered.

The lower division of the *Annulose* sub-kingdom is represented by the tracks of sea-worms, and by the tubes of Tube-worms. The higher division of the *Articulates* appears to have been represented wholly by the Crustaceans, no Spiders, Centipedes, or Insects, having been hitherto detected. When we consider, however, that these creatures are almost all air-breathers, and that the Silurian strata are all marine, we need not be surprised at this. The two most important groups of Silurian *Crustacea* are the *Trilobites* and the *Eurypterids*. The former abound in all the divisions of the Silurian series, and some of the characteristic forms have been already figured (Figs. 62, 63). They are somewhat allied to the living Horse-shoe Crabs, and are distinguished (Fig. 79) by having the

head protected by a semicircular shield, while the body is more or less distinctly three-lobed.

The *Eurypterids* (Fig. 45) were mostly of very large size, some having attained a length of several feet. They are decidedly allied to the recent Horse-shoe Crabs (*Limulus*). They

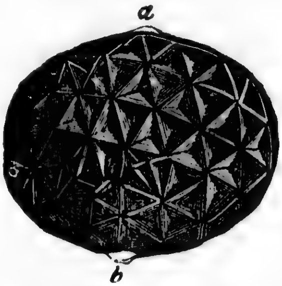


Fig. 78.—*Echinosphærites Balticus*, a Lower Silurian *Cystidean*.—*a*, Mouth; *b*, Point of attachment of the stem.

Fig. 79.—*Trinucleus concentricus*, a Lower Silurian Trilobite.

are confined to the upper portion of the Silurian series, and pass upward into the succeeding formation of the Old Red Sandstone.

The sub-kingdom *Mollusca* is very largely represented in the Silurian deposits. The lowly-organized shell-fish known as *Brachiopods* are so abundant in all parts of the system, that the Silurian period has been spoken of as the "age of Brachiopods." Illustrations will be found in Figs. 64–66, and 71–73. The true bivalves and the univalve shell-fish are also represented by many and varied forms. The highest division of the Mollusks—that of the *Cephalopoda* or Cuttle-fish order—is represented by an enormous number of forms more or less closely allied to the Pearly Nautilus. Some idea of the abundance of these organisms may be obtained from the fact that M. Barrande has described over a thousand species from the Silurian rocks of Bohemia alone. The most abundant and characteristic of the Silurian Cephalopods are the *Orthoceratites* (Gr. *orthos*, straight; *keras*, horn). These resembled the Nautilus in essential structure, but the shell was straight and not curved into a spiral (Fig. 81). The size of some of the

Orthocerata was very remarkable, specimens having been found of a length of seven or eight feet. In nearly allied forms the shell was more or less curved (Fig. 80), but it is never coiled into a close spiral as in the Nautilus.

SILURIAN CEPHALOPODS.

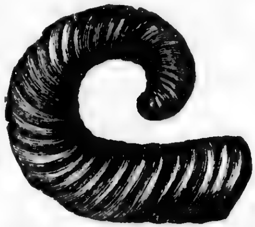


FIG. 80.—*Trochoceras giganteus.* ½ nat. size.

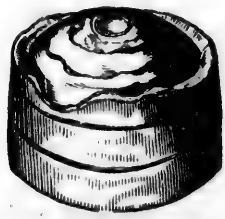


FIG. 81.—Fragment of *Orthoceras Ludense.*

The sub-kingdom *Vertebrata* is only represented in the highest division of the Silurian rocks, and there only in its lowest forms, namely by Fishes. The discovered remains, however, indicate the existence in the later Silurian seas of two orders of fishes, Ganoid fishes, allied to the living Sturgeon, and Shark-like fishes, allied to the living Port Jackson Shark. It is noticeable, also, that no undoubted traces have hitherto been discovered of the lower orders of fishes, and that remains of these may be looked for in the inferior portion of the Silurian system.

CHAPTER XVII.

OLD RED SANDSTONE.

THE Silurian rocks are succeeded upward by a great system of rocks, mainly of the nature of sandstones and conglomerates, to which the name of *Old Red Sandstone* has been applied. The name *Devonian* formation is also employed to designate these same strata, rocks supposed to belong to this period being largely developed in Devonshire, in England. It is probable, however, that the Devonian rocks represent a portion only of the Old Red Sandstone, and that they cannot be regarded as the full equivalent of the Old Red Sandstone of other regions. The term "Devonian" may, however, when thus understood, be usefully employed as a general term for all the strata which intervene between the Silurian System and the succeeding formation of the Carboniferous rocks.

The uncertainty as to the exact position of the Devonian rocks of Devonshire in the series of the Old Red Sandstone, or the uncertainty as to whether they represent the Old Red Sandstone in whole or in part, arises from this—that though both formations are fossiliferous, the peculiar fossils of each are never found associated together. The peculiar fossils of the Old Red Sandstone proper are not found in the rocks of Devonshire; and the fossils of the latter, though found in equivalent strata on the Continent of Europe, do not occur in the beds to which the name of Old Red Sandstone was originally applied. This, however, may be largely due to the fact that, while the Devonian strata are undoubtedly marine in their origin, there seems reason to conclude that the Old Red Sandstone proper was, in part at any rate, a fresh-water deposit. The two groups, therefore, might be truly contemporaneous, and yet might not contain the same fossils.

OLD RED SANDSTONE OF BRITAIN.—The Old Red Sand-

stone is preëminently a British formation, and is better developed in Scotland than anywhere else in the world. It is divisible into three divisions, the Lower, Middle, and Upper Old Red Sandstone.

The *Lower Old Red* reposes with perfect conformity upon the highest beds of the Upper Silurians, the two formations appearing to pass into one another by an intermediate series of "passage-beds," which contain large Crustaceans of the family of the *Eurypterids.* The Lower Old Red consists mainly of massive conglomerates, with sandstones, shales, and concretionary limestones. Its organic remains consist chiefly of plants, Crustaceans, and fishes. The plants are sometimes abundant, but are always imperfect, though they show occasionally woody tissue, and exhibit decided indications of a terrestrial origin. The Crustacea are abundant, and are all *Eurypterids*, similar to, though specifically distinct from, the Eurypterids of the Upper Silurian (Fig. 45). The most characteristic fossils, however, of the Lower Old Red are *fishes*, some of which are peculiar to this period. Among these is the singular genus *Cephalaspis*, which agrees with the *Pteraspis* of the Ludlow rocks in having the head covered with a buckler of enamelled plates (Fig. 82).

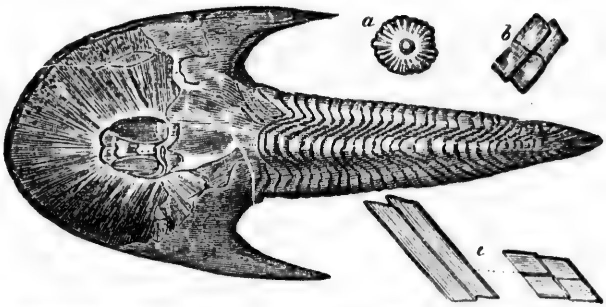


FIG. 82.—*Cephalaspis Lyellii*, a Ganoid fish of the Lower Old Red Sandstone.—*a*, One of the scales covering the head; *b*, *c*, Scales from different parts of the body and tail.

The *Middle Old Red* of Scotland consists of dark-gray flagstones, bituminous, flaggy shales, and conglomerates, sometimes accompanied by shales having irregular calcareous nodules imbedded in them. The fossil remains are chiefly fishes, with one Crustacean, and a few plants.

The *Upper Old Red* of Scotland consists of pebbly conglomerates, sandstones and shales, and contains many fishes,

a good many fragments supposed to belong to sea-weeds, and some undoubted land-plants. One of these, a fern (Fig. 83), has been found in beds of the same age in Ireland, and has been described under the name of *Adiantites Hibernicus.* It is accompanied with a large fresh-water mussel (*Anodonta Jukesi*), and with fish-remains. The plants of the Upper Old Red as a whole approximate in general characters to those of the coal-formation. The fishes of the Upper Old Red are all specifically and generically distinct from those of the Carboniferous formation. One of the most characteristic forms is figured below (Fig. 84).

Fig. 83.—Fragment of *Adiantites Hibernicus.*

In Britain generally, while the Lower Old Red is always conformable with the Upper Silurian, and the Upper Old Red is almost always conformable to the Lower Carboniferous rocks, there appears to be always a want of conformity between the Lower and Upper Old Red. Wherever this unconformity, however, has been observed, the Middle Old Red appears to be wanting; while

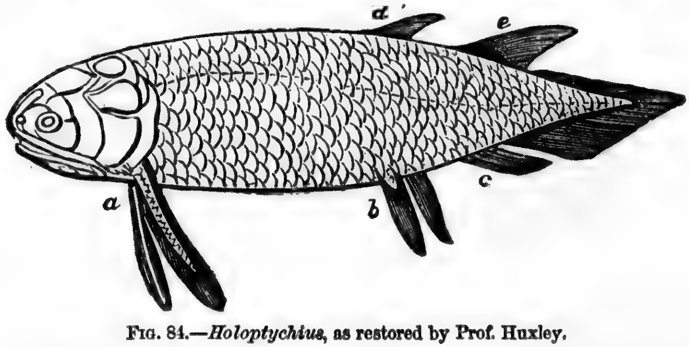


Fig. 84.—*Holoptychius*, as restored by Prof. Huxley.

no systematic break can be detected in the equivalent rocks in North America.

Rocks of Devonshire.—In North and South Devon there occurs underlying the Carboniferous rocks a great series of strata which has been regarded as the equivalent of the Old Red Sandstone. Though certainly referable, in great part at any rate, to the period of the Old Red Sandstone, it does not appear that the Devonian rocks can be regarded as the *equiva-*

lent of the Old Red Sandstone of Scotland. The Devonian rocks, however, are largely represented on the Continent of Europe, and they are richly fossiliferous; though they do not contain any of the characteristic *Crustaceans*, and only one or two generic representatives of the characteristic *fishes* of the Scotch Old Red.

The Devonian rocks of Devonshire consist essentially of greenish slates, alternating with sandstones, conglomerates, and well-developed bands of blue crystalline limestone and calcareous slates. They have been divided into three groups, distinguished by local names. The most characteristic fossils of the Devonian rocks are Corals, Brachiopods, and Trilobites, with Crinoids, and bivalve and univalve Mollusks. Among the *Brachiopods*, the most characteristic forms belong to the genus *Spirifer* (Fig. 85), and are distinguished by their being greatly

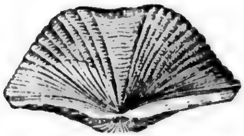


FIG. 85.—*Spirifer disjunctus.* Upper Devonian.

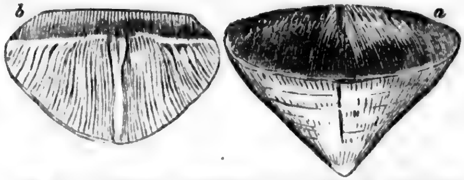


FIG. 86.—*Calceola sandalina.*—*a*, Cup of the coral; *b*, Lid.

extended from side to side. These fossils are so abundant in certain strata of the same age in Germany, that the name of "Spirifer-sandstone" is given to the beds. Among the *corals*, one of the most remarkable is the *Calceola* (Fig. 86), which is furnished with a lid or cover, and was long regarded as being referable to the *Brachiopods*.

Trilobites are abundant in many Devonian beds, and in many cases belong to Silurian genera. A very abundant and characteristic species is the *Phacops latifrons* (Fig. 87).

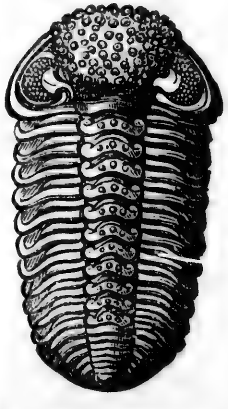


FIG. 87.—*Phacops latifrons.* Devonian of Europe, Asia, and North and South America.

DEVONIAN ROCKS OF NORTH AMERICA.—In no country in the world probably is there a finer and more complete exposition of the strata intervening between the Silurian and Carboniferous formations, than in the United States. The following are the main subdivisions of the Devonian rocks of the State of New

York, in which, probably, the series is most typically displayed (*see* section, Fig. 87½):

1. Oriskany period (Oriskany Sandstone), 2. Corniferous period (comprising the Cauda-Galli grit, Schoharie grit, and Upper Helderberg group),	Lower Devonian.
3. Hamilton period (comprising the Marcellus, Hamilton, and Genesee groups), 4. Chemung period (comprising the Portage and Chemung groups), 5. Catskill period (Catskill Sandstone),	Upper Devonian.

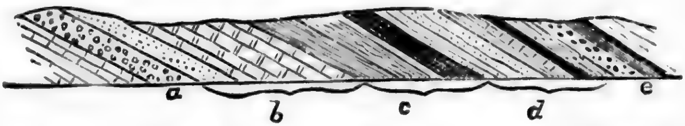


FIG. 87½.—Generalized section of the Devonian rocks of the State of New York.—*a*, Oriskany sandstone; *b*, Corniferous series; *c*, Hamilton series; *d*, Chemung series; *e*, Catskill series.

1. The *Oriskany Sandstone* has a thickness of from five to thirty feet, and is named from the town of Oriskany, in Oneida County, New York. The rock is mostly a coarse-grained, yellowish sandstone, replete with fossils, of which the most numerous and characteristic forms are *Brachiopods*. The fossils of the Oriskany sandstone are in many respects related to those of the highest Silurian rocks, and the determination of this formation as the base of the Devonian series is to a great extent an arbitrary one.

2. The *Corniferous Period* is characterized by sandy strata in its lower portion, and calcareous beds above. The lowest beds (Cauda-Galli grit) are characterized by a singular spiral fossil, which has been supposed to be a seaweed. The calcareous division (Upper Helderberg group) extends from Eastern New York to beyond the Mississippi, and contains a profusion of fossils, especially Corals, Brachiopods, and Trilobites. The corals especially are so abundant in some beds as to leave no doubt that the rock is the remains of an ancient coral-reef. In this period, also, are the first discovered remains of *Fishes* as yet found in the American Continent. These remains are referable partly to shark-like fishes, and partly to *Ganoids*, and it is noticeable that their occurrence in America is considerably later than in Britain, where fishes are found in the Upper Silurians. The name "Corniferous" is derived from the fact

that one of the limestones of this period (Corniferous limestone) contains numerous nodules of hornstone, a kind of imperfect flint. The hornstone occurs much in the same way as the flints in chalk, and, as we shall see hereafter, its origin is a similar one, for it has been shown to contain remains of similar organisms. The name *Corniferous* is, therefore, derived from this fact (Lat. *cornu*, horn; *fero*, I bear). The maximum thickness of the rocks of the Corniferous period appears to fall short of 400 feet, and it is much less than this in most localities.

3. The rocks of the *Hamilton Period* are shales, sometimes highly carbonaceous, at the base (Marcellus shales), shales, flags, and limestones (Hamilton beds) in the middle, and shales again at the top (Genesee shales). The maximum thickness of the entire series is short of fourteen hundred feet. In this series have been detected the remains of true Coniferous trees, allied to the living Pines, along with plants resembling the living Club-mosses, but attaining a comparatively gigantic size (*Lepidodendron* and *Sigillaria*). The most characteristic fossils of the period are bivalve Mollusks and Brachiopods, and among the latter are some of the broad-winged *Spirifers* so characteristic of the Devonian of Europe.

4. The *Chemung Period* is composed wholly of sandy and shaly beds, and has a maximum thickness of little more than three thousand feet. Land-plants are not uncommon in this period, and sea-weeds are abundant. The animal remains are chiefly *Bivalve Mollusks* allied to the recent scallops and pearl-oyster, *Brachiopods* and *Cephalopods*.

5. The rocks of the *Catskill Period* are also sandy and shaly, the arenaceous beds being generally red in color, and often conglomeratic. Their thickness varies from 2,000 to as much as 6,000 feet. Fossils are very scarce, and consist chiefly of land-plants and fragments of fishes. Among the latter are the remains of a *Holoptychius*, similar to a species which is characteristic of the Upper Old Red in Scotland (Fig. 84).

Life of the Devonian Period.—Taken as a whole, and especially as regards its development in North America, the life of the Devonian period appears to be transitional between that of the underlying Silurian and overlying Carboniferous series. The *Plants* of the Devonian period are, upon the whole, very closely allied to those of the Coal-measures, in most cases agreeing generically, and sometimes being even specifically identical. We find here, for the first time, the remains of regular exogenous trees, resembling the modern Pines and

Cypresses, and referable to the gymnospermous section of the Dicotyledons. We find also here for the first time true ferns (Fig. 83), many of which resemble those of the Coal-measures. Lastly, we have here the characteristic carboniferous plants *Sigillaria* and *Lepidodendron*. These are believed to be most nearly allied to the Cryptogamic Club-mosses of the present day, but they attained the altitude of trees. A species of *Sigillaria* from the Chemung group is figured below (Fig. 88). Allied to these, but not found in the coal, is the genus *Psilophyton*, which has been established by Dr. Dawson, of Montreal, for a plant which is very common in the Devonian of Canada and New York. The same high authority has determined the occurrence of wood of an exogenous tree referable to the angiospermous division of the Dicotyledons, and resembling, therefore, our ordinary trees and shrubs. In connection with these remains of an old land-surface, we may notice that the Devonian formation in America has yielded the first traces of air-breathing animals, in the form of *Insects*, somewhat allied to the May-flies of the present day.

FIG. 88.—*Sigillaria Chemungensis*. Fragment of the stem (after Hall).

The lowest forms of animal life are represented by sponges. The next division of the animal kingdom (*Cœlenterata*) is represented by one or two Graptolites—the last of this singular family—and by very numerous and varied forms of corals. Crustaceans are abundant, and are represented by numerous Trilobites, by gigantic Eurypterids, and by some

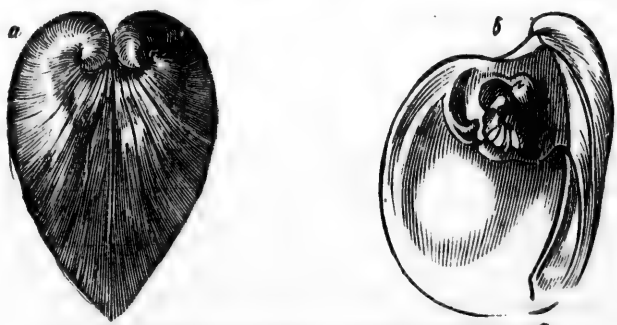


FIG. 89.—*Megalodon cucullatus*: a Devonian Lamellibranch.

small forms allied to the living water-fleas. The *Mollusca* are largely represented in Devonian time, and the *Brachiopods* are especially predominant. The true bivalve Mollusks are abundant, and some of the forms are very characteristic of the period. This is the case with the species figured above (Fig. 89). Univalve Mollusks are also not uncommon, but some of the *Cephalopods* are more important and more characteristic. The forms allied to the *Nautilus* of the present day are represented by the genus *Clymenia* (Fig. 90), which agrees with

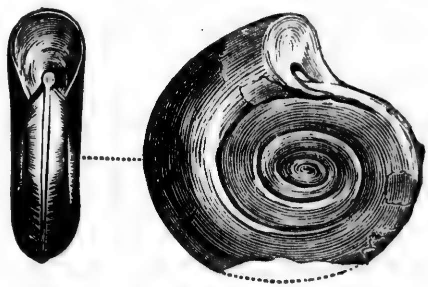


FIG. 90.—*Clymenia linearis*—Devonian of Europe.

the Nautilus in having simply curved partitions between the chambers of the shell. Here also occur for the first time the forerunners of the great family of the *Ammonites*, in the form of the genus *Goniatites*. The shell in this genus resembles that of the Nautilus in shape, but the partitions are lobed, and the siphuncle is placed on the back of the shell. *Orthoceratites* still continue to be represented.

The sub-kingdom of the Vertebrates is still represented by fishes only; but these are so abundant that the Devonian Period has been termed the "Age of Fishes." The order of the Ganoids, with shining bony scales, is represented most numerously by many singular forms, of which two have been already figured (Figs. 82 and 84). Besides the Ganoids, however, are found the fin-spines of fishes believed to be most nearly allied to the living Port-Jackson Shark, and belonging, therefore, to another and a higher order. It is further to be remembered, as already remarked, that the appearance of fishes is later in America than in Britain. The earliest remains of fishes in Britain have been found in the Upper Silurian rocks (at the base of the Ludlow Series); but no American fossil fishes have hitherto been found in any stratum earlier than the lower portion of the Corniferous series.

CHAPTER XVIII.

CARBONIFEROUS FORMATION.

OVERLYING the great formation of the Old Red Sandstone, or Devonian rocks, sometimes unconformably but more often in perfect conformity, we have the large and important series of the *Carboniferous Rocks*, so called because workable beds of coal are more commonly developed in this than in any other formation. It must not be forgotten, however, that coal is not exclusively a Carboniferous product, but that workable seams of coal occur in several formations younger than the Carboniferous. In all cases, too, the coal forms but a very small proportion of the actual thickness of the Carboniferous rocks, occurring in comparatively thin beds intercalated in a great series of sandstones, shales, and limestones.

The Carboniferous rocks are largely developed in Britain, on the Continent of Europe, and in North America, and are known to occur in other parts of the world also. Their general composition, however, is, comparatively speaking, so uniform, that it will be sufficient to take a general view of the formation without considering each area separately. As a general rule, the Carboniferous rocks may be divided into the following three groups, from below upward:

1. The *Carboniferous Slates* and *Mountain Limestone*, mainly and most typically calcareous. Sometimes termed the sub-carboniferous group.

2. The *Millstone Grit*, essentially arenaceous and conglomeratic.

3. The *Coal-measures*, composed of alternating shales, sandstones, and other strata, with workable beds of coal.

I. The CARBONIFEROUS, SUB-CARBONIFEROUS, or MOUNTAIN, LIMESTONE, constitutes ordinarily the base of the Carboniferous system. In Ireland, however, and elsewhere the

lowest beds of the Carboniferous series are slates and grits, which attain a maximum thickness of 5,000 feet, and have been termed the *Carboniferous Slates* (Fig. 91, *a*). Their fossils are partially referable to good Carboniferous types, and

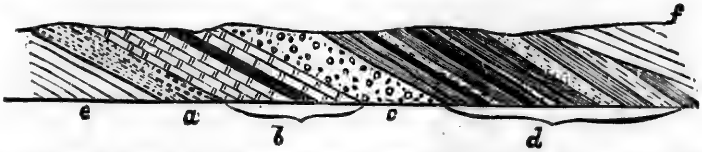


FIG. 91.—General section of the Carboniferous rocks.—*a*, Carboniferous slates; *b*, Carboniferous limestone; *c*, Millstone grit; *d*, Coal-measures; *e*, Devonian rocks; *f*, Permian rocks.

partly to Devonian forms, so that they may be regarded as passage-beds. The Carboniferous limestone proper in its most typical development, as in Wales and the west of England, consists of a great mass of nearly pure limestone, from 1,000 to 2,000 feet thick, with a few beds of shale. In other places, however, it is more or less broken up into a series of different beds of limestone, alternating with sandstones, grits, and shales, and sometimes containing beds of coal. In North America it is never purely calcareous, but consists mainly, or entirely, of sandstones and shales, sometimes with thin beds of coal, or deposits of clay iron-ore. Westward, however, it becomes more highly calcareous.

As the Carboniferous limestone is generally a marine formation, its fossils are usually those of sea-animals. In those places, however, in which beds of coal occur in this series, plant-remains are tolerably abundant and agree in their characters with those of the Coal-measures. In some places, also, the series includes beds of undoubted fresh-water origin. As a rule, however, marine fossils characterize the Carboniferous limestone, and they are generally very abundant. The great limestones of this formation in particular are almost made up of fragmentary or perfect fossils, chiefly referable to Corals, Crinoids, and Brachiopods. The Corals (Fig. 92) are especially abundant, the rock sometimes having all the features of an old coral-reef. Two of the more common and widely-distributed forms are figured here (Figs. 92, 93). *Crinoids* are extremely abundant, the entire rock in many places being composed of little else than the broken stems of these beautiful fossils, when it is spoken of as "Crinoidal Limestone." It is rare, however, to find unbroken specimens. The body and

CARBONIFEROUS LIMESTONE CORALS.

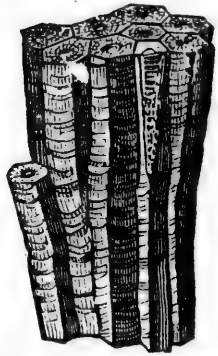


FIG. 92.—*Lithostrotion basaltiforme.*

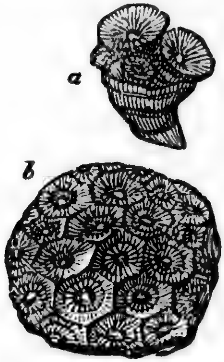


FIG. 93.—*Lonsdaleia floriformis.*

arms of a characteristic species are figured below (Fig. 94). Nearly allied to the true Crinoids are the *Pentremites*, which are very characteristic of some beds of this formation. They differed, however, from the Crinoids in not possessing the jointed feathery arms of the latter. Here, also, for the first time we meet with true Sea-urchins belonging to two genera, and differing in some important respects from all living forms.

Among the most abundant and characteristic fossils of the Carboniferous limestone are the very numerous *Brachiopods*, of which certainly the most characteristic are a number of species of the very well-marked genus *Producta* (Fig. 95).

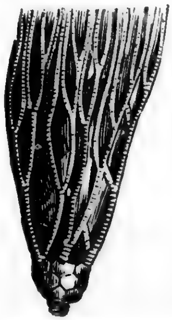


FIG. 94.—*Cyathocrinites planus.*

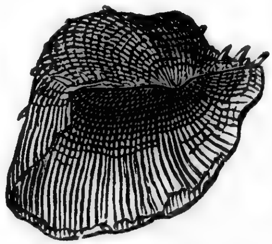


FIG. 95.—*Producta semireticulata.*

Members of this genus are found all over the world, wherever the Lower Carboniferous rocks are developed; and they some-

times attain a very large size. Along with these are *Spirifers* and other species. Bivalve and univalve Mollusks are of common occurrence, and some of both have even been found retaining their original bands of color. *Cephalopodous* shells are not uncommon, especially large *Orthoceratites* and *Goniatites.* One of the commonest forms of the latter, both in Europe and North America, is *Goniatites crenistria* (Fig. 96).

The *Crustacea* are chiefly represented by small forms, allied to the living water-fleas, the bivalve cases of which are extraordinarily abundant in certain beds. Here, also, we have for the last time *Trilobites,* but these die out finally before the deposition of the Coal-measures.

The remains of Vertebrate animals, with one exception, are referable to fishes. The exception to this is constituted by the footprints of an Amphibian, allied probably to the living newts, which has been discovered in North America. These tracks have been described under the name of *Sauropus primævus*, and they constitute as yet the earliest indication of animal life higher in the scale than fishes. The fishes of the Carboniferous limestone are mostly referable to genera which more or less resemble the Port-Jackson Shark, and which are represented merely by their broad crushing teeth (Fig. 97). Besides these there are teeth of true Sharks (*Cladodus*), along with numerous fin-spines.

Fig. 96.—*Goniatites crenistria.*

Fig. 97.—*Teeth of Cochliodus contortus.*

II. The Millstone Grit.—The highest beds of the Carboniferous limestone are succeeded, usually conformably but sometimes unconformably, by a series of sandy and gritty beds which have been termed the *Millstone grit.* In its most typical form the Millstone grit consists of a series of hard quartzose sandstones, the component grains of which are sometimes so large as to be more properly called small pebbles, when the rock becomes a fine conglomerate. In other

cases regular conglomerates are present, and there are sometimes shales, limestones, and thin beds of coal. The thickness of the Millstone grit varies from 1,000 to 1,700 feet as a rule; but sometimes its thickness is very greatly diminished. Fossils are scarce, and offer no peculiarity.

III. THE COAL-MEASURES.—The Coal-measures proper succeed the millstone-grit conformably, and consist of a great series of shale, sandstone, grit, and coal, attaining a total thickness, when well developed, of from 7,000 to 15,000 feet. Except in Scotland, where workable coal-seams occur below the horizon of the millstone-grit, it is mostly from the true Coal-measures that coal is obtained; the largest and most productive coal-fields of the world occurring in Britain, North America, and Belgium. In their mineral nature, the Coal-measures, all over the world, exhibit a wonderful *general* uniformity of composition. They consist, namely, of dark, often nearly black, earthy and laminated shales, yellow, brown, and purple sandstones, sometimes spotted, but very rarely red in color, along with occasional beds of limestone and clay iron-ore, and beds of coal of varying thickness. These alternating beds may follow one another in any order, and may be repeated over and over again, the total thickness sometimes reaching the enormous amount of 14,000 feet, or nearly three miles. In the South Wales coal-field the series consists as usual of sandstones, shales, and coals, alternating with one another, and indicating a slow but probably intermittent depression of the area which they now occupy. In this coal-field there are about 80 distinct beds of coal, each of which—as we shall subsequently see—represents an ancient land-surface. Each of these beds reposes upon a sandy shale or clay, which is known as the "underclay" or "floor" of the coal, and through which spread numerous fossils referred to the genus *Stigmaria*, and now known to be the roots of plants (*Sigillaria*). Each seam is also surmounted by a bed of shale, forming the so-called "roof" of the coal, and in this are found numerous flattened and compressed branches and stems of plants.

The phenomena just indicated lead us to a consideration of the vegetable remains of the Coal-measures, and of the origin of coal. The Lower Carboniferous rocks, as already said, are mainly marine in their origin, and contain marine fossils. The Coal-measures, on the other hand, are characterized by the occurrence of terrestrial organisms, chiefly but not exclusively of a vegetable nature, along with the remains of brackish-water, fresh-water, or sometimes marine animals. The most abun-

dant and characteristic fossils of the Coal-measures are plants, of which there is a great variety of very remarkable forms, mostly differing widely from existing plants. Not only is the coal* itself merely compressed vegetable matter, but more or less perfect plant-remains occur throughout the entire series. The more important plants of the Coal-measures are the following:

Ferns are very numerous in the Carboniferous series, and several hundred species have been described. Some of them were tree-like, others more of the size of the common ferns, and many are extremely like living species.

About forty species of plants have been referred to the genus *Lepidodendron* (Fig. 98), which is believed to have been most closely allied to our living Club-mosses (*Lycopodiaceæ*), but of gigantic size. The remains referred to *Lepidodendron* consist of cylindrical stems or trunks covered with

FIG. 98.—Branching-stem, 49 feet long, of *Lepidodendron*.

FIG. 99.—Stem with bark and leaves of *Lepidodendron Sternbergii*.

leaf-scars, marking the points where the leaves were formerly attached. Sometimes the leaves may be found attached to the stem, and in some rare cases the cones or fruit may be found in connection with the ends of the branches. These cones, however, are more commonly found in a detached condi-

* Coal consists of nearly pure carbon, with small proportions of hydrogen and oxygen, and a minute quantity of mineral matter. *Bituminous* coal is coal containing a considerable quantity of gaseous ingredients, and burns with a bright-yellow flame. *Anthracite* is coal containing a smaller quantity of gaseous matter, burning with greater difficulty, and with a bluish flame. All coal is composed of successive layers, or laminæ, and sometimes distinct vegetable structure can be detected.

tion, and they have been described under the name of *Lepidostrobus*. No living member of the Club-mosses or Ground-pines attains a greater height than three feet; but some species of *Lepidodendron* must have been lofty trees, for specimens are known to have exceeded fifty feet in length.

Of common occurrence, also, in the coal-measures are the vegetable remains known as *Calamites* (Figs. 100–102). These consist of cylindrical, furrowed, and striated stems, divided at intervals by joints, or articulations. The lower extremity (Fig. 102) tapers off into a conical point, where the stem was doubtless attached. The original view as to the nature of Calamites referred them to gigantic Horse-tails (*Equisetacea*); and the tendency of modern investigation is

Fig. 100.—*Calamites cannæformis.*

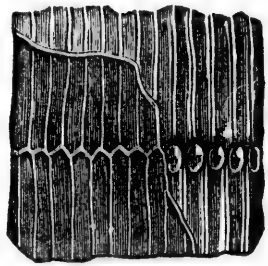


Fig. 101.—*Calamites Sucowii.*

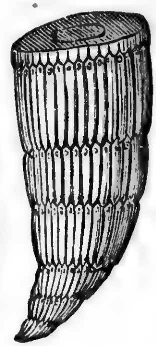


Fig. 102.—Root-termination of a Calamite.

to confirm this view, though it is rejected by competent authorities. True Horse-tails (*Equisetites*) certainly do occur in the coal, and, as the size of these is considerable, the great size of the Calamites need not necessarily render this view at all improbable.

Among the most abundant and most important of the coal-plants are those referred to the genera *Sigillaria* and *Stigmaria*, which are now known to be nothing more than different parts of the same plant. Many species of *Sigillaria* are known, and some of these attained a great height (as much as 60 or 70 feet in some instances), though they do not appear to have branched except close to their summit. They consist of fluted stems (Fig. 103), marked with longitudinal ridges, between which are rows of single or double scars, indicating the points of attachment of the leaves. In numerous instances *Sigilla-*

riæ have been found in their original upright position; and in many cases it appears that the interior must have decayed much more rapidly than the exterior, so that, if upright, the interior may be filled with sandstone, and, if prostrate, the stem has been completely crushed and flattened. As regards size, stems of *Sigillaria* vary from a foot to as much as five feet in diameter, with a height of from 30 to 70 feet. The well-known fossil *Stigmaria* (Fig. 104) has now been shown to be nothing more than the root of *Sigillaria*, the actual connection between the two having been in many instances demonstrated. *Stigmaria* occurs in the form of long, compressed, or rounded fragments, the external surface of which is covered with shallow tubercles, each of which has a little pit or depression in its centre. From each of these pits, in perfect examples, there proceeds a long cylindrical process, or rootlet;

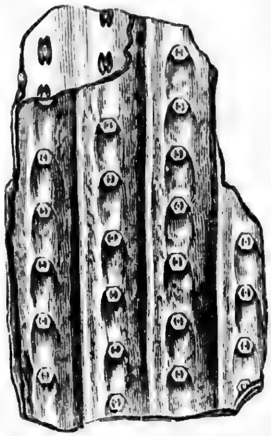


FIG. 103.—Fragment of *Sigillaria lævigata*. (Brongniart.)

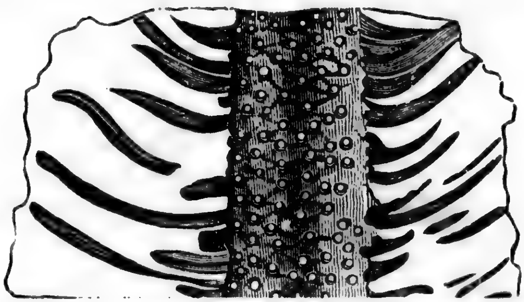


FIG. 104.—Fragment of *Stigmaria ficoides*. ¼ natural size.

but these in ordinary examples have disappeared. The exact botanical position of the *Sigillariæ* is uncertain; but the most probable view would regard them as a peculiar group of Gymnospermous Exogens.

Of the remaining plants of the Coal-measures may be mentioned true Coniferous trees, related to the recent Norfolk Island Pines (*Araucaria*). Flowering plants are of very rare occurrence, and it is doubtful if any true Dicotyledonous Angiosperms have hitherto been detected.

ORIGIN OF COAL.—As regards the origin of coal, only two theories need be mentioned: *firstly*, that coal is the result of the drifting together and accumulation by water of enormous quantities of vegetable matter of all kinds; and, *secondly*, that beds of coal are due to the gradual decay, upon the surface where it grew, and through long periods, of a dense vegetation, so that each coal-seam represents an ancient land-surface. It is possible that in some instances the first theory may be correct. It is possible, namely, that in some rare instances a great river may have brought down drift-wood and other vegetable matter in sufficient amounts to have ultimately formed a bed of coal. The purity of coal, however, and its general freedom from earthy or sandy matter—difficult to explain upon any theory—becomes wholly inexplicable upon this view. In the great majority of cases, and most probably in all, coal-beds have been formed by the gradual growth and decay, throughout long periods, of a rank vegetation. The correctness of this view is shown, not only by the absence of impurities in coal, but by the common occurrence of upright stems and trunks still retaining their vertical position (Fig. 105). In

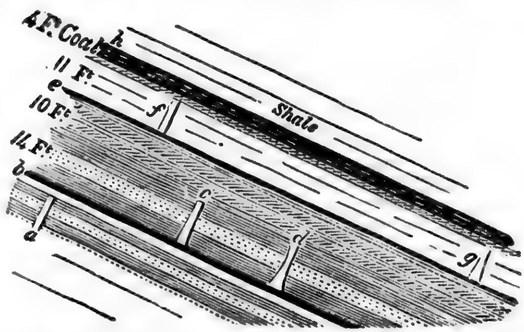


FIG. 105.—Erect fossil trees. Coal-measures, Nova Scotia.

other cases, again, further and still more convincing evidence can be obtained in support of this view from the phenomena of the "underclay," which forms the "floor" of the coal-seam. This "underclay," upon this view, ought to represent the ancient *soil* upon which grew the plants which formed the coal. In the underclay, accordingly, we find *Stigmaria* branching freely in every direction, while in the coal itself, or in the shale which forms the "roof" of the coal, are the stems and trunks of *Sigillaria*, of which the *Stigmariæ* are the *roots*.

The general belief, then, about the Coal-measures, is that they have been deposited in a manner which is very closely similar to, if not exactly identical with, the way in which are produced the deltas of our great rivers, such as the Ganges or Mississippi. Such deltas at the present day form vast alluvial flats, or plains, very little elevated above the sea, composed of the fine mud and sediment brought down by the river, and supporting a dense and luxuriant vegetation. To explain the phenomena of the coal-measures, we must suppose that after the lapse of a certain period, when a sufficient amount of vegetable matter had been accumulated upon such a marshy tract, a submergence took place beneath the waters of the sea. The vegetable accumulations would then gradually be buried beneath a series of sedimentary deposits, such as sandstones or shales, which would contain the remains of marine animals. Or it might be, if the submergence were slight, that the sunken area should be covered by the river itself, or by brackish water. In this case, the fossils of the beds deposited above the vegetable layer would be those of fresh water, or those proper to brackish water. If, now, an elevation took place, or sufficient sediment were deposited to counteract the previous subsidence, a fresh land-surface would be formed upon which a fresh swamp or jungle would be produced. The same depression, repeated a second time, would convert this in turn into another bed of coal, again surmounted by marine, fresh-water, or brackish-water beds; and so the process might be repeated indefinitely, till such a vast series as the coal-measures of Nova Scotia might be produced.

In accordance with this generally-received theory as to the origin of coal, we find in the Coal-measures the remains of various air-breathing animals, both Vertebrate and Invertebrate. If each seam of coal with its underclay represents an ancient land-surface, this is just what we might have expected. We find, then, the remains of various true Insects, Scorpions, Spiders, several species of the class of the Centipedes (*Myriapoda*), and air-breathing Shell-fish, allied to living Snails. Associated with these are a number of Newt-like animals, most, if not all of which, are referable to a peculiar and now extinct group of the *Amphibians*. These have been called *Labyrinthodonts*, from the complex and labyrinthine structure of the teeth. Several of these attained a very large size, and a figure of one of the smallest is given hereafter (Fig. 106).

Also in accordance with the above theory we find the beds associated with the coal to contain the remains of marine,

fresh-water, or brackish-water animals. Among these may be mentioned Crustaceans allied to the living Water-fleas and King-crabs, bivalve Shell-fish, Cephalopods, Brachiopods, and numerous fishes, some of which were of large size and highly predaceous. The marine fossils, as a rule, have a general agreement with the forms of the Carboniferous Limestone.

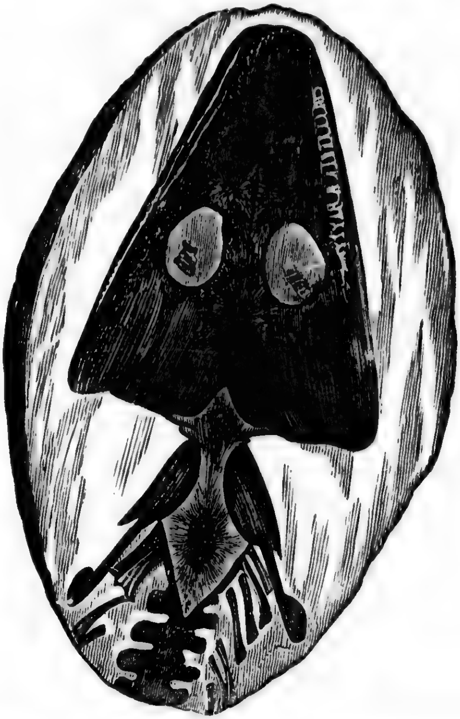


FIG. 106.—*Archegosaurus minor*, a fossil Amphibian from the coal-measures (Saarbrück).

LIFE OF THE CARBONIFEROUS PERIOD.—As regards the plants of this period, it is sufficient to point to the great predominance of *Cryptogamous*, as compared with *Phanerogamous* plants, the Gymnospermic Exogens being almost the only representatives of the latter.

The lowest forms of animal life (*Protozoa*) are represented by the shells of *Foraminifera*, which are sometimes so abundant as almost to make up the whole of certain limestones. The *Cœlenterates* are represented by numerous Corals, which abound

especially in some of the limestones of the Lower Carboniferous series. The *Echinodermata* chiefly figure in the form of Crinoids and allied forms, but we now meet for the first time with true Sea-urchins. The *Articulates* are well represented by both air-breathing and water-breathing forms. The *Trilobites* make their last appearance in this period, but they were represented by but a few forms, and these died out before the Coal-measures were deposited. The *Crustacea* are represented, however, by numerous minute forms with bivalve shells, like the living Water-fleas (Fig. 108), and by larger forms nearly allied to the recent Horseshoe Crabs (Fig. 107). The air-

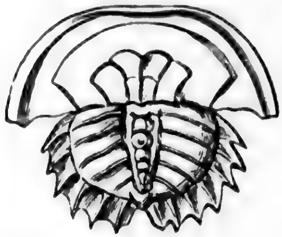


FIG. 107.—*Limulus rotundatus*, a fossil horseshoe crab from the coal.

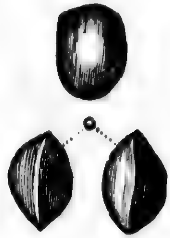


FIG. 108.—Small bivalve Crustaceans (*Cythere inflata*), natural size and magnified. (After Murchison.)

breathing *Articulates* are represented by Insects, Spiders, Scorpions, and Centipedes—in fact, by all the great classes at present in existence. The *Mollusca* are largely represented in all their great divisions. *Brachiopoda* are numerous, and the two leading genera are *Producta* (Fig. 95) and *Spirifer* (Fig. 109). Bivalve Mollusks, especially those allied to the Scallops

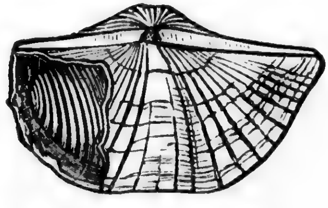


FIG. 109.—*Spirifer trigonalis*.

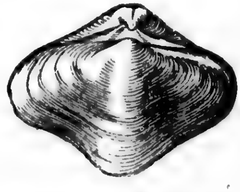


FIG. 110.—*Spirifer glaber*.

and Pearl-mussels, occur in great plenty, and there are also many Univalves. The *Cephalopoda* are represented chiefly

by *Orthoceratites*, often of great size, and by *Goniatites* (Fig. 96). Vertebrate life is pretty abundant, and we have now numerous Amphibians, in addition to the fishes, which are so characteristic of the preceding Devonian period. The fishes are mainly *Ganoids*, and have all unsymmetrical or unequally-lobed tails. The Amphibians all belong to the extinct order of the *Labyrinthodonts*.

CHAPTER XIX.

PERMIAN ROCKS.

THE Carboniferous series is succeeded by a group of beds, which complete the Palæozoic formations, and which were termed *Permian Rocks* by Sir Roderick Murchison, from the province of Perm, in Russia, where they are extensively developed. Formerly these rocks were grouped with the succeeding formation of the Trias under the common name of "New Red Sandstone." This name was given them because they contain a good deal of red sandstone, and because they are superior to the Carboniferous rocks, while the Old Red Sandstone is inferior. Nowadays, however, the term "New Red Sandstone" is rarely employed, unless it be for red sandstones and associated rocks, which are seen to overlie the Coal-measures, but which contain no fossils by which their exact age may be made out. Under these circumstances it is sometimes convenient to employ the term "New Red Sandstone." The New Red, however, of the older geologists is now broken up into the two formations of the Permian and Triassic rocks, the former being the top of the Palæozoic series, and the latter constituting the base of the Mesozoic.

The Permian rocks, as a rule, repose unconformably upon the underlying Carboniferous rocks, but seem to pass upward conformably into the Trias, in most instances. The division, therefore, between the Permian and Triassic rocks and, consequently, between the Palæozoic and Mesozoic series, is not founded upon any marked physical break, but upon the difference in the life of the two periods.

The Permian rocks exhibit their most typical features in Russia and Germany, though they are very well developed in parts of Britain, and they occur in North America. When well developed, they exhibit three main divisions: a lower set

of sandstones, a middle group, generally calcareous, and an upper series of sandstones, constituting respectively the Lower, Middle, and Upper Permians (Fig. 111).

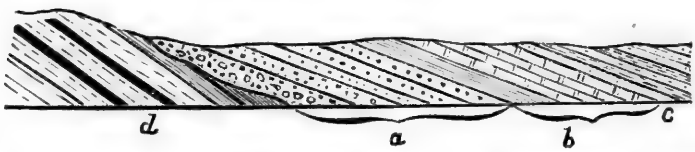


FIG. 111.—Generalized section of the Permian rocks.—*a*, Lower Permian rocks; *b*, Middle Permians; *c*, Upper Permians; *d*, Coal-measures.

In Russia, Germany, and Britain, the Permian rocks consist of the following members:

1. The *Lower Permians* (Fig. 111, *a*), consisting mainly of a great series of sandstones, of different colors, but usually red. The base of this series is often constituted by massive breccias with included fragments of the older rocks, upon which they may happen to repose; and similar breccias sometimes occur in the upper portion of the series as well. The thickness of this group varies a good deal, but may amount to 3,000 or 4,000 feet.

2. The *Middle Permians* (Fig. 111, *b*), consisting, in their typical development, of laminated marls, or "marl-slate," surmounted by beds of magnesian limestone (the "Zechstein" of the German geologists). Sometimes the limestones are degenerate or wholly deficient, and the series may consist of sandy shales and gypsiferous clays. The magnesian limestone, however, of the Middle Permians is, as a rule, so well marked a feature that it was long spoken of as *the* Magnesian Limestone.

3. The *Upper Permians* (Fig. 111, *c*), consisting of a series of sandstones and shales, or of red or mottled marls, often gypsiferous, and sometimes including a bed of limestone.

In North America, the Permian rocks appear to be confined to the region west of the Mississippi, being especially well developed in Kansas. Their exact limits have not as yet been made out, and their total thickness is not more than a few hundred feet. They consist of sandstones, conglomerates, limestones, marls, and beds of gypsum.

LIFE OF THE PERMIAN PERIOD.—The Permian rocks have yielded a very considerable number of plants, most of which are specifically distinct from the plants of the Coal-measures.

Though the species, however, are distinct, many of the Permian genera date from the antecedent Carboniferous period. Thus, besides several genera of Carboniferous ferns, the Permian rocks contain the well-known genera *Lepidodendron* and *Calamites;* but *Sigillaria* and *Stigmaria* have hitherto not been shown to have survived the Coal period. Conifers allied to the living firs are not uncommon, and one of the more characteristic is figured below (Fig. 112).

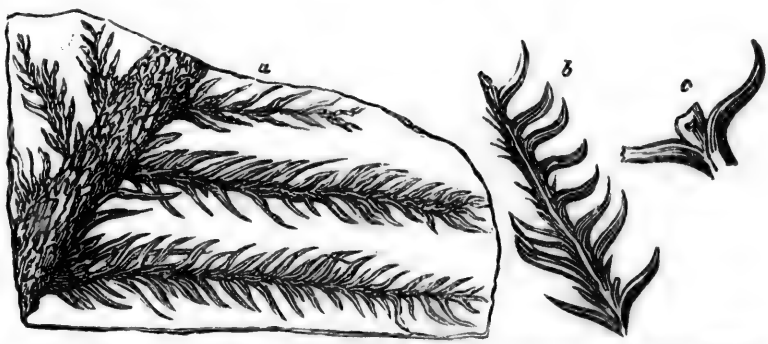


FIG. 112.—*Walchia piniformis*, a Permian Conifer (after Gutbier).—*a*, Branch; *b*, Twig; *c*, Leaf, magnified.

Corals are rare in the Permian rocks, and the older types have now almost wholly disappeared. Echinoderms are also scarce, and require no special notice. The most abundant and most characteristic fossils of the Permian period—after the plants—are Mollusks and Fishes. Besides forms, such as the Lace-coral, allied to the living Sea-mosses and Sea-mats, the lower Mollusks are represented by various Brachiopods. Among these are representatives of the genera *Producta* (Fig. 113), and *Spirifer* (Fig. 115). Some of the Brachiopods agree

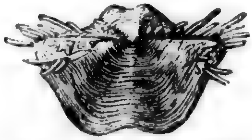


FIG. 113.—*Producta horrida.*

FIG. 114.—*Lingula Credneri.*

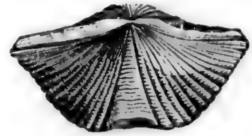


FIG. 115.—*Spirifer undulatus.*

specifically with those of the Carboniferous period, and they are all of Palæozoic types. In addition to the Brachiopods

there are numerous Bivalve Mollusks, with some Univalves and Cephalopods. The fishes of the Permian rocks are all of Palæozoic types, being mostly Ganoids, and having invariably unsymmetrical or unequally-lobed tails (Fig. 116). The species

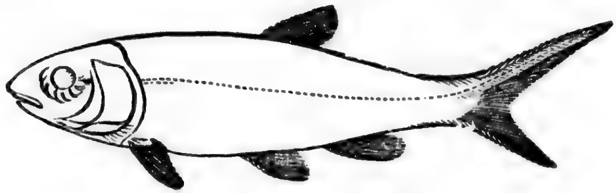


FIG. 116.—Restored outline of *Palæoniscus*.

are peculiar, but most of the Permian genera are also found in the Coal-measures. One of the most characteristic genera, viz., *Palæoniscus*, is figured above. Besides fishes, the Middle Permians have yielded the bones of a true reptile, which is known by the name of *Protorosaurus*. It is the oldest known example of a true lizard, and is believed to be most nearly allied to the great Monitors of the old world.

CHAPTER XX.

TRIASSIC FORMATION.

We come now to the consideration of the great *Mesozoic*, or Secondary series of formations, consisting, in ascending order, of the Triassic, Jurassic, and Cretaceous systems. The Triassic group forms the base of the Mesozoic series, and corresponds with the higher portion of the New Red Sandstone of the older geologists. Like the Permian Rocks, and as implied by its name, the *Trias* admits of a subdivision into three groups, a Lower, Middle, and Upper Trias (Fig. 117). Of

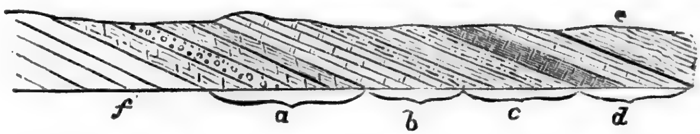


Fig. 117.—Generalized section of the Triassic rocks.—*a*, Bunter Sandstein; *b*, Muschelkalk; *c*, Keuper; *d*, Rhætic beds; *e*, Lias; *f*, Permian rocks.

these subdivisions the middle one is wanting in Britain; and all have received German names, being more largely and typically developed in Germany than in any other country. Thus, the Lower Trias is known as the *Bunter Sandstein*, the Middle Trias is called the *Muschelkalk*, and the Upper Trias is known as the *Keuper*.

I. The lowest division of the Trias is known as the *Bunter Sandstein* (Fig. 117, *a*), from the generally variegated colors of the beds which compose it (German, *bunt*, variegated). The Bunter Sandstein of the Continent of Europe consists of red and white sandstones, with red clays, and thin limestones, the whole attaining a thickness of about 1,500 feet. The term "marl" is very generally employed to designate the clays of

the Lower and Upper Trias, but the term is inappropriate, as they contain no lime, and are, therefore, not genuine marls. In Britain the Bunter Sandstein consists of red and mottled sandstones, with unconsolidated conglomerates, or "pebble-beds," the whole having a thickness of about 1,200 feet. The Bunter Sandstein, as a rule, is very barren of fossils. In Britain it has yielded little, except some singular hand-like footprints (Fig. 118), which were originally ascribed to an

FIG. 118.—Footprints of *Cheirotherium*, in Saxony.

unknown animal under the name of *Cheirotherium* (Gr. *cheir*, hand; *ther*, beast), but which are now known to have been made by a large Amphibian belonging to the order of the *Labyrinthodonts*. On the Continent the Bunter has yielded a considerable number of plants, chiefly ferns and conifers, not one of which occurs in the Upper Trias. The most characteristic of these plants is the Coniferous tree, *Voltzia*, of which an example is given in Fig. 119.

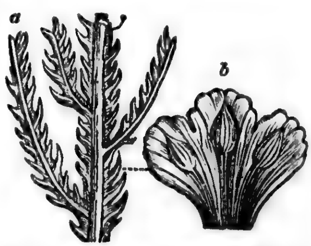


FIG. 119.—*Voltzia heterophylla*.—*b*, Portion of the same, magnified to show the fructification.

II. The Middle Trias is not developed in Britain, but constitutes in Germany a formation termed the *Muschelkalk* (Germ. *Muschel*, mussel; *Kalk*, limestone), from the abundance of fossil shells which it contains. It consists of gray or yellowish limestones (Fig. 117), sometimes magnesian, including occasional beds of gypsum and rock-salt. Among the most characteristic fossils of the Muschelkalk are the shells of *Ceratites* (Fig. 120), a Cephalopod somewhat allied to the Pearly Nautilus, but belonging to the same family as the *Ammonites*. *Ceratites*, however, is distinguished by having the partitions which divide the chambers of the shell (Fig. 120, *c*) simply denticulated, and not by any means elaborately frilled as in the *Ammonites*. True *Ammonites* and *Belemnites*, both, as we shall see, highly characteristic of the later Secondary rocks, are wanting in the Muschelkalk. Very characteristic, also, of the Muschelkalk is the beautiful stone

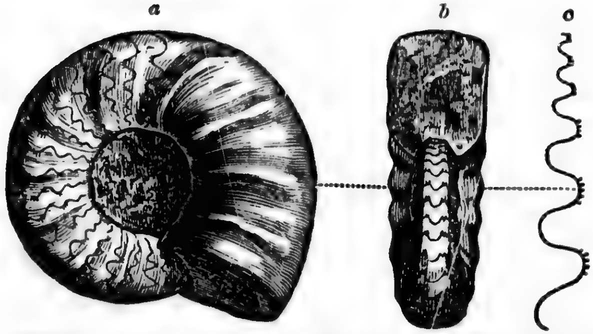


FIG. 120.—*Ceratites nodosus.*—*a*, Side view; *b*, Front view; *c*, Outline of one of the partitions dividing the chambers of the shell.

lily (*Encrinus liliiformis*, Fig. 121), heads and stems of which are found in considerable abundance. Fishes are far from uncommon in the *Muschelkalk*, and there are also the remains of several reptiles.

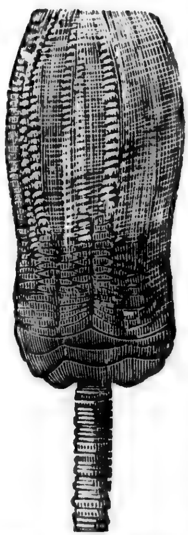


FIG. 121.—*Encrinus liliiformis.*

III. The Upper Trias or Keuper consists of about 1,000 feet of sandstones, marls, or clays, generally red or green, with rock-salt and gypsum, and sometimes beds of dolomite. The Keuper in Britain is very unfossiliferous; but it contains in Germany a good many plants, some of which (such as *Calamites*) are of Carboniferous genera, while most agree more with the plants of the Lias and Oolites, consisting chiefly of Ferns, Horse-tails, Conifers, and Cycads. Besides these, there are the remains of Fishes, with some Reptiles. The Keuper passes upward, both in Britain and Germany, into a set of beds of a very remarkable nature, which are known by various names, but may be spoken of here as the *Rhætic* beds, as they occur in the Rhætic Alps. The most characteristic fossils of these beds are three shells—a Cockle (*Cardium Rhæticum*, Fig. 122), a Scallop (*Pecten Valoniensis*, Fig. 123), and a Pearl-mussel (*Avicula contorta*, Fig. 124). This last is so abundant that the beds are often spoken of as the *Avicula contorta beds.*

Besides these, there occurs in this series of beds a peculiar stratum known as the "bone-bed," from its being almost entirely

made up of the teeth and scales of various fishes, some of which are figured below (Figs. 125–127). In addition to fish-remains, the bone-bed has yielded the teeth of two small Mammals, the earliest fossil quadrupeds as yet known to us. Of these, the

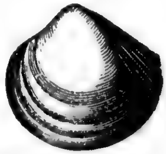


FIG. 122.—*Cardium Rhæticum.* Nat. size.

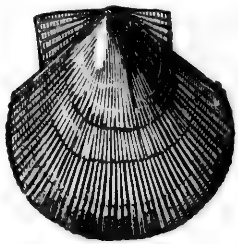


FIG. 123.—*Pecten Valoniensis.* ⅓ nat. size.

FIG. 124.—*Avicula contorta.* Nat. size.

first discovered and most celebrated is a little predacious animal, probably marsupial, which has been described under the

FIG. 125.—Teeth of *Hybodus plicatilis.*

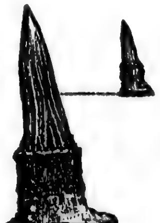


FIG. 126.—Tooth of *Saurichthys apicalis;* nat. size and magnified.

FIG. 127.—Scale of *Gyrolepis;* nat. size and magnified.

name of *Microlestes antiquus*, and which is only known by one of its grinders (Fig. 128).

FIG. 128.—Different views of the molar tooth of *Microlestes antiqvus.*

In the Austrian Alps, the *Avicula contorta* beds are underlaid by nearly 3,000 feet of calcareous strata which must be referred to the period of the Upper Trias, and which are

replete with fossils, most of which are Mesozoic, while a few are of Palæozoic types. Thus, we find in these beds the Palæozoic forms *Orthoceras* and *Goniatites*, which make here their final appearance. Mixed with these ancient Cephalopods, occurs the characteristic Triassic form *Ceratites* (Fig. 120), and, in addition to these, we find true *Ammonites* and *Belemnites*, which form such a marked feature in the life of the later Jurassic period. The same wonderful intermixture of ancient with modern types is seen also in the other fossil Mollusks of these strata, but we may especially remember that in the Upper Trias we lose sight of the genera *Orthoceras* and *Goniatites*, and for the first time meet with *Ammonites* and *Belemnites*.

TRIASSIC ROCKS OF NORTH AMERICA.—Rocks of Triassic age occur in several areas in the United States between the Appalachians and the Atlantic seaboard; but they show no such triple division as in Germany. The rocks of this age consist of red sandstones, sometimes shaly or conglomeratic, and occasionally with beds of impure limestone. One of the most celebrated of the Triassic areas of the United States is in the valley of the Connecticut River, where the beds have yielded the footprints of various different animals. Among these are a number of paired footsteps of different sizes and with different characters, and undoubtedly produced by animals which walked upon two legs only. Some of these prints are four-toed, and these have been produced by reptiles, for it is now known that some extinct reptiles walked, habitually or occasionally, upon two legs. Others (Fig. 129), again, are three-toed, and these have generally been ascribed to birds.

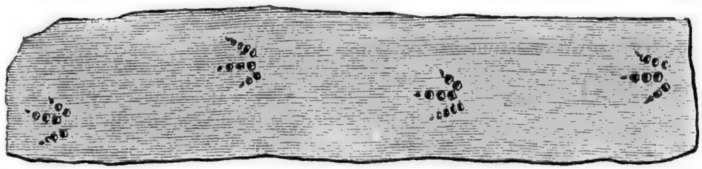


FIG. 129.—Three-toed footprints from the Trias of the Connecticut Valley.

If this supposition be correct, we have here the earliest indications yet known to us of the existence of birds. Other more extensive areas where Triassic rocks appear at the surface are found west of the Mississippi, on the slopes of the Rocky Mountains, where the beds consist of sandstones and gypsiferous marls. Besides numerous reptiles, and the supposed

tracks of birds, the American Trias has yielded the remains of plants, insects, fishes, and Mammals. The fishes are remarkable because we here meet for the first time with forms having symmetrical or equally-lobed tails. The Mammals are represented by the lower jaw of a small quadruped which has been named *Dromatherium sylvestre*, and is believed to find its nearest living ally in the little insectivorous and marsupial *Myrmecobius* or Banded Ant-eater of New South Wales.

ORIGIN OF ROCK-SALT.—As has been already mentioned, rock-salt is commonly found in beds accompanying strata of Triassic age, and sometimes attaining a thickness of 90 to 100 feet or more. The salt may be quite pure, or may be mixed with more or less earthy impurity, and the association of rock-salt with Triassic strata is so common that the Trias is often spoken of as the *Saliferous* system. As a very general rule, rock-salt is found to be associated with sulphate of lime or gypsum, and very generally also with magnesian limestones, red sandstones, and red and variegated clays. Still, strata of this kind are often destitute of salt, and salt may occur in rocks of a different nature. As to the origin of rock-salt, the generally-received theory is, that it has been formed by the evaporation of the water of inland seas or lagoons, which communicate at intervals with the ocean. It cannot be said, however, that we have as yet any theory which will explain all the phenomena of the occurrence of rock-salt, or which can be applied to all cases.

LIFE OF THE TRIASSIC PERIOD.—The Triassic period, as regards its plants and animals, is in many respects intermediate between the Palæozoic and later Mesozoic deposits, while being itself decidedly Mesozoic. Among the plants we have some Palæozoic types (such as *Calamites*), but there is no longer a marked predominance of Cryptogams, and the leading forms are Ferns, Conifers, and Cycads.* As regards the Invertebrates of the Trias, the intermixture of Palæozoic and Mesozoic types is especially well seen in the *Mollusca*, and particularly in the *Cephalopods*. The straight *Orthoceratites* appear here for the last time, as do the *Goniatites*, in which the shell was coiled up like the Nautilus, but the partitions between the chambers were lobed and not simple. Characteristically Triassic is the *Ceratite* (Fig. 120), in which the shell is somewhat intermediate between the *Goniatites* and the *Ammonites*, the partitions between the chambers of the shell

* The *Cycads* are nearly related to the *Conifers* (Fir-tribe), but differ greatly in external form and habit. They look like tree-ferns, and are all natives of warm climates. An Australian species is figured at p. 181.

being denticulated. Lastly, in the Upper Trias, appear for the first time true *Ammonites* (Fig. 133), in which the partitions between the chambers of the shell are wonderfully folded and frilled at their edges. With these also are *Belemnites* (Fig. 132), which are really the *internal* shells or skeletons of cuttle-fishes.

The *Vertebrates* are represented by Fishes, Amphibians, Reptiles, Birds, and Mammals, in fact by all the great subdivisions of the vertebrate sub-kingdom. The fishes are all *Ganoids*, but some of them for the first time exhibit the symmetrical or equally-lobed tails, which characterize the great majority of living fishes. The Amphibians are represented by *Labyrinthodonts*, mostly of gigantic size; but this order of the class, which appeared first in the Carboniferous rocks, does not appear to have survived the Triassic period. The true Reptiles are represented by lizards, swimming reptiles of various kinds, and often of large size, crocodile-like species, and others wholly unlike any thing that we know as existing at the present time. The class of Birds is represented doubtfully by the footprints of the American Trias (Fig. 129); but if these are rightly determined, then the class has its commencement in this period. Mammals are for the first time represented by two or three small quadrupeds, which are only known to us by their teeth or lower jaws, but which appear to belong to the *Marsupials* or pouched quadrupeds, the lowest order of the class *Mammalia*. They appear to be most nearly allied to the living Banded Ant-eater and Kangaroo-rat of Australia.

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CHAPTER XXI.

JURASSIC OR OOLITIC SERIES.

SUCCEEDING to the Trias, we have a great series of rocks which are known as the *Oolitic Rocks*, from their commonly containing oolitic limestones, or as the *Jurassic Series*, from their being largely developed in the mountain range of the Jura, on the western borders of Switzerland. The Jurassic rocks are very extensively developed in Britain, where they consist of the following members in ascending order (Fig. 130):

I. Lias.
II. Lower Oolites (consisting of the Inferior Oolite, Fuller's Earth, Great Oolite, Stonesfield Slate, etc.).
III. Middle Oolites (Oxford Clay and Coral Rag).
IV. Upper Oolites (Kimmeridge Clay, Portland Stone, and Purbeck beds).

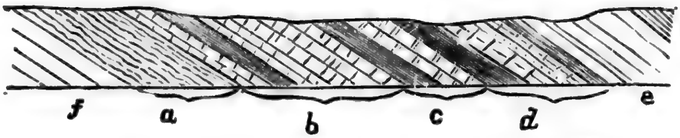


FIG. 130.—Generalized section of the Jurassic rocks.—*a*, Lias; *b*, Lower Oolites; *c*, Middle Oolites; *d*, Upper Oolites; *e*, Weald Clay; *f*, Rhætic beds.

I. The *Lias* (Fig. 130, *a*) succeeds the uppermost beds of the Trias with perfect conformity, and passes upward, generally conformably, into the lowest beds of the Lower Oolites. It consists essentially of a great series of bluish or grayish laminated clay, alternating with thin bands of blue or gray limestone, the whole assuming at a distance a characteristically striped and banded appearance. The total thickness of

the Lias may be over 1,000 feet, and it teems with fossils, of which only a few of the more characteristic can be mentioned here.

Brachiopoda are very abundant, and it is noticeable that we have here the last appearance of the Palæozoic genus *Spirifer*.

Bivalve shell-fish are common, and one of the most characteristic species is a singular curved oyster, the *Cryphæa incurva* (Fig. 131). Of all the Liassic fossils, however, the most abundant and characteristic are the remains of *Cephalopods*, allied on the one hand to the living Cuttle-fishes, and on the other to the Pearly Nautilus. Under the first head come the *Belemnites* (Fig. 132), or, as they are commonly called, "thunderbolts," from their conical form. These really are the internal supports or skeletons of animals like the living Cuttle-fishes or Squids; and they consist of a long, tapering, fibrous body, enclosing above a hollow chambered portion, and terminating in front in a horny plate, which is rarely preserved in a fossil condition. Under the second head we have true *Nautili*, and a vast abundance of different species of *Ammonites*, of which two characteristic forms are figured below (Figs. 133, 134).

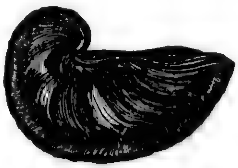


Fig. 131.—*Gryphæa incurva.* Lias.

Fig. 132.—*Belemnites elongatus.* Lias.

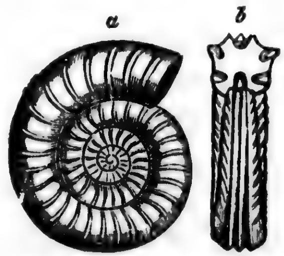


Fig. 133.—*Ammonites Bucklandi*, ½ nat. size.—*a*, Side view; *b*, Front view.

Fig. 134.—*Ammonites planorbis*, ½ nat. size.

Echinoderms occur not uncommonly in the Lias, the commonest being *Crinoids*, the form figured below being especially characteristic and abundant (Fig. 135.) Besides these, we find true Sea-urchins, Brittle-stars, and Star-fishes.

FIG. 135.—*Extracrinus Briareus.* ⅙ nat. size.

Fishes are very largely represented, both by *Ganoids* and by forms allied to the recent Port-Jackson Shark, the teeth and fin-spines of the latter being especially abundant (Fig. 136).

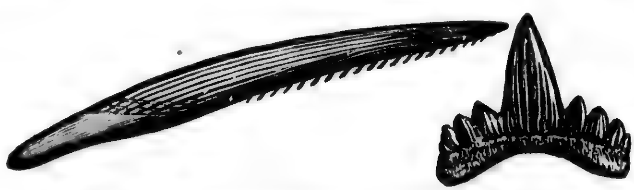


FIG. 136.—*Hybodus reticulatus.*—*a*, Fin-spine; *b*, Tooth.

Lastly, the Lias swarms with the bones, teeth, and petrified droppings or "coprolites" of large marine reptiles, which constitute the genera *Ichthyosaurus* and *Plesiosaurus*, and which will be spoken of at greater length in treating of the life of the Oolitic period.

II. The *Lower Oolites* (Fig. 130, *b*) consist of calcareous freestones (Inferior Oolite), shales, clays, and marls (Fuller's-earth), fine-grained Oolitic limestones (Great Oolite), with calcareous flags at the base (Stonesfield slate), and shelly limestones and calcareous sandstones (Forest-marble and Cornbrash), the whole having a thickness of from 400 to 500 feet. In Yorkshire the Lower Oolites consist of limestones with carbonaceous shales and thin seams of coal, which are sufficiently extensive and constant to be worked for coal. Of this age, also, is probably the coal-field of Brora, in Sutherlandshire, in the north of Scotland.

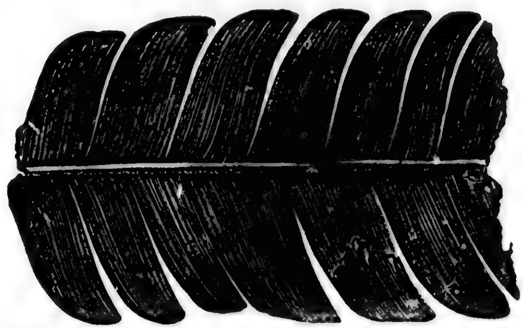


FIG. 137.—*Pterophyllum comptum.* Lower Oolites, Yorkshire.

Among the fossils of the Lower Oolites, plants are very abundant in some places, the leading forms being Ferns and Cycads. The specimen figured above (Fig. 137) is a Cycad belonging to the genus *Pterophyllum.*

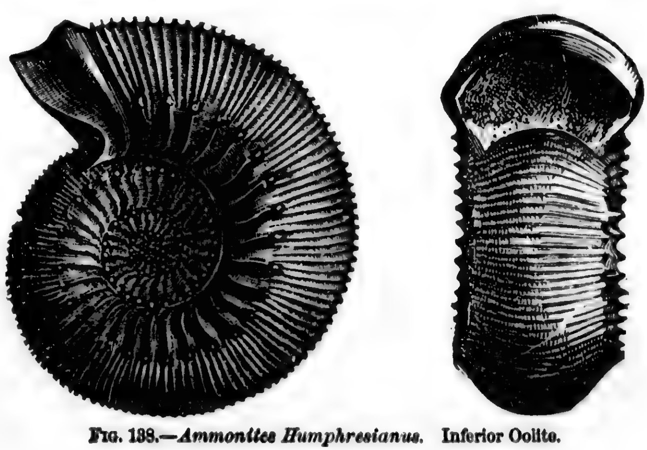


FIG. 138.—*Ammonites Humphresianus.* Inferior Oolite.

Mollusca are common in the Lower Oolites, Univalves especially so, but there are also Brachiopods and true Bivalves. Cephalopods are not so common, but there are some characteristic *Ammonites* (Fig. 138). The *Echinodermata* are represented by Sea-urchins and Crinoids, the most characteristic form among the latter being the Pear Encrinite (*Apiocrinus rotundus*, Fig. 139), which sometimes occurs in layers. Corals, also, are abundant in some of the limestones. Among the most remarkable, however, of the organic remains of the Lower Oolites are three small Mammals which are found in the Stonesfield slate, and which were long the oldest known representatives of their class. Two of these have been described under the names of *Amphitherium* and *Phascolotherium*, and are certainly Marsupial, the latter (Fig. 140) presenting a close resemblance to the living opossums. The third forms the genus *Stereognathus*, and its exact affinities are still doubtful.

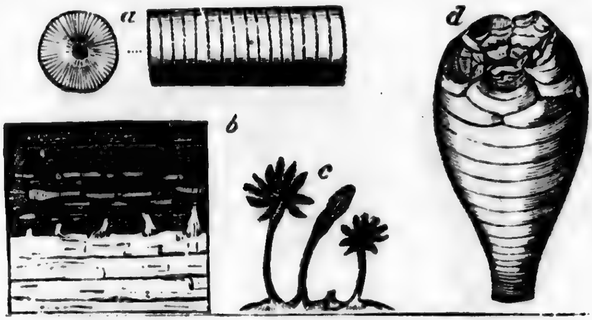


FIG. 139.—*Apiocrinus rotundus*.—*a*, Stem and one of the joints; *b*, Section showing the Encrinites growing on limestone and enveloped above by clay (now shale); *c*, Three perfect individuals represented as growing, but of reduced size; *d*, Head, without the arms.

FIG. 140.—Lower jaw of *Phascolotherium Bucklandi*.—*a*, Natural size; *b*, Molar tooth magnified.

III. The *Middle Oolites* are composed of a great mass of dark-blue, tenacious clay (Oxford clay), with a maximum thickness of 700 feet, surmounted by from 150 to 250 feet of limestones known as the Coral-rag, from the number of corals contained in them. The fossils of the Oxford clay are chiefly

Ammonites and *Belemnites*, the little *Belemnites hastatus* (Fig. 141) being a characteristic species. The Coral-rag may

FIG. 141.—*Belemnites hastatus.* Oxford Clay.

be regarded as an ancient coral-reef, and contains numerous corals, some of which attained a very large size. A characteristic species is *Thecosmilia annularis* (Fig. 142). Besides corals, however, the Coral-rag contains numerous bivalve and univalve Shell-fish, with sea-urchins and other fossils.

FIG. 142.—*Thecosmilia annularis.* Coral-rag.

IV. The *Upper Oolites* consist in Britain of laminated, sometimes carbonaceous or bituminous clays (Kimmeridge clay), forming the base of the group, and having a thickness of 500 or 600 feet. These are succeeded by sandstones and limestones (Portland stone) of about 120 feet in thickness; and the formation is capped by a remarkable group of alternating strata of fresh-water, brackish-water, and marine beds, with old land-surfaces, the whole known as the Purbeck beds, and having a united thickness of about 150 feet. Of the same age as the Upper Oolites in Britain is the Solenhofen slate of Bavaria, an exceedingly fine-grained stone, which is largely used in lithography, and is celebrated for the number and beauty of its organic remains, especially those of Vertebrates. The number of fossils in the Upper Oolites is so great that it is impossible to give those characterizing the minor subdivisions, and it will be sufficient to indicate some of the more striking forms.

Mollusca are very numerous, and are represented by marine forms in the marine beds, but by fresh-water forms in many of the beds of the Purbeck group. Oysters are especially abundant, and there is one bed in the Purbecks 12 feet thick, and composed entirely of the valves of a singular oyster, *Ostrea distorta* (Fig. 143). Corals occur in some of the beds, and there are also Sea-urchins, and numerous little bivalved Crustaceans allied to the living Water-fleas. The Solenhofen slates

FIG. 143.—*Ostrea distorta.* Middle Purbecks.

have yielded numerous *Crustacea* of higher types, along with numerous insects, fishes, Tortoises, and other Reptiles, among which the most singular are the Flying-lizards, known as *Pterodactyles* (Fig. 144). Besides these, the Solenhofen slates have yielded the first actual remains of birds in the form of the bones and feathers of the *Archæopteryx macrura* (Fig. 150). The characters of this extraordinary bird will be spoken of later on. Lastly, a thin bed of marl in the Middle Purbeck beds has given up the bones of no less than *fourteen* distinct species of small Mammals. These quadrupeds are all of small size, and hardly any of their bones have hitherto been discovered, except separate branches of the lower jaw; so that it is very difficult to refer them to their proper place in the class *Mammalia.* One genus, however, viz., *Plagiaulax* (Fig. 145), appears to be almost certainly Marsupial, and to be most nearly allied to the living Kangaroo-rats.

FIG. 144.—*Pterodactylus crassirostris* (skeleton).

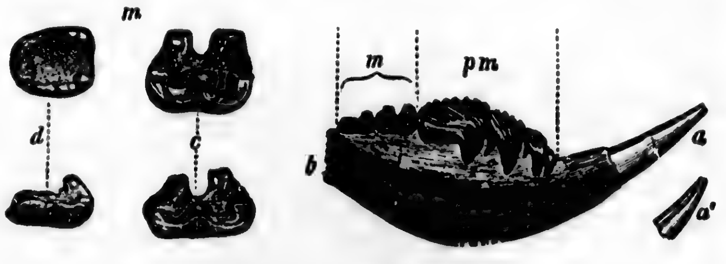


FIG. 145.—Lower jaw and teeth of *Plagiaulax minor.* Purbeck beds.

JURASSIC ROCKS OF NORTH AMERICA.—Rocks belonging to the Jurassic series, in the form of limestones and marls, have been detected by their fossils in the Laramie Mountains and in other portions of the Rocky Mountains, and also at various points in Arctic America. The extent, however, of these beds is unknown, and no subdivisions have hitherto been established in them.

LIFE OF THE OOLITIC PERIOD.—The vegetation of the Jurassic period is characterized by the abundance of ferns, Coniferæ, and Cycadaceous plants, and the rarity of Angio-

spermous Exogens. The Cycads are especially abundant throughout the whole Oolitic series, and the subjoined cuts (Figs. 146, 147) exhibit the trunk of a fossil form side by side with a living species, with its crown of feathery leaves.

FIG. 146.—*Cycadeoidea megalophylla*, a fossil Cycad. Purbeck beds.

The *Brachiopoda* of the Jurassic series are decidedly less numerous than in the older rocks, and they approximate more to living forms. Bivalve and univalve Mollusks are numerous, and upon the whole present a decided likeness to those of existing seas. *Cephalopods* are extraordinarily numerous, and

FIG. 147.—*Zamia spiralis*, a living Cycad. Australia.

Ammonites and *Belemnites* may be said to be preëminently *the* fossils of the Oolitic rocks. The Crinoids are now considerably diminished in number, but the *Echinodermata* are represented by an increased number of Sea-urchins, Brittle-stars, and Star-fishes. The *Crustacea* of the Oolitic rocks show a very decided advance in structure, and we now meet with forms resembling our living Crabs and Lobsters. Insects also are numerous.

Fishes are very abundant in parts of the Oolitic series, the majority being still *Ganoids*, though most of these have the symmetrical tail of most modern fishes. Besides these, there are many fishes allied to the living Port-Jackson Shark (*Cestracion*), and true Sharks and Rays. Reptiles are still more numerous than in the Trias, their great abundance in these formations and in the Cretaceous epoch having led to the naming the Mesozoic period the "Age of Reptiles." The *Labyrinthodonts* of the later Palæozoic and earlier Mesozoic formations have now disappeared, and we have no longer the same forms of true reptiles as characterize the Trias. We have, however, four reptiles of especial interest which are the types of so many extinct orders. The first of these is the *Megalosaurus*, a gigantic terrestrial reptile, which belongs to the order *Deinosauria* (Gr. *deinos*, terrible; *saura*, lizard). This order is better represented in the earlier portion of the Cretaceous period. Secondly, we have a group of extraordinary flying reptiles, *Pterosauria* (Gr. *pteron*, wing; *saura*, lizard), characterized by having one finger of the hand enormously elongated for the support of a leathery membrane by which flight was effected. The best known genus of this order is *Pterodactylus* (Fig. 144), of which several species are known, varying in size from a crow, up to an expanse of wing of 15 to 20 feet, or more. Thirdly, we have two gigantic reptiles, the types of two distinct orders, the remains of which are very common in the Oolitic series. One of these is the *Ichthyosaurus* (Gr. *ichthus*, a fish; *saura*, lizard), of which many species are known. The *Ichthyosaurus* (Fig. 148) was a marine, swimming reptile, fully adapted to an aquatic life by having a horizontal tail-fin, and by having all the limbs converted into flippers or swimming-paddles. The jaws are very long, and are furnished with numerous conical teeth, so that the animal must have been highly predaceous. The *Plesiosaurus* (Gr. *plesios*, near to; *saura*, lizard) was also a marine animal, inhabiting the sea, and likewise had the limbs completely enveloped in the integuments, and thus converted into powerful swimming-paddles. The *Plesiosaurus*, however, differs from the short-necked and voracious *Ichthyosaurus* in having much shorter jaws and an enormously and disproportionately elongated neck. Many species of both of these huge reptiles are known, and they attained in some instances a length of over 30 feet.

The class of Birds is represented by the tail, tail-feathers, and some detached bones of a single bird, the *Arcæopteryx*

Fig. 148.—Skeleton of *Ichthyosaurus communis*, restored by Conybeare and Cuvier.—*a*, Vertebræ of the back.

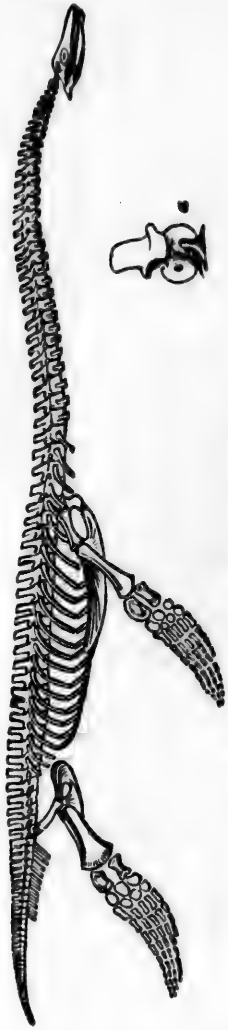


Fig. 149.—Skeleton of *Plesiosaurus dolichodeirus*, restored by Conybeare.—*a*, Vertebræ of the neck.

macrura (Fig. 150), which was about as large as a pigeon. This extraordinary bird differed from all living birds in having two free claws to the wing, and in having the tail long and composed of separate vertebræ, each of which carried a single feather on each side (Fig. 150, A). The tail, therefore, except

for the presence of feathers, was long and lizard-like. In all living birds, on the other hand, the tail-feathers spring in a bunch from the last few vertebræ of the tail, and the tail terminates in a single upright, ploughshare-shaped bone, which can be erected and depressed at will (Fig. 150, D, E).

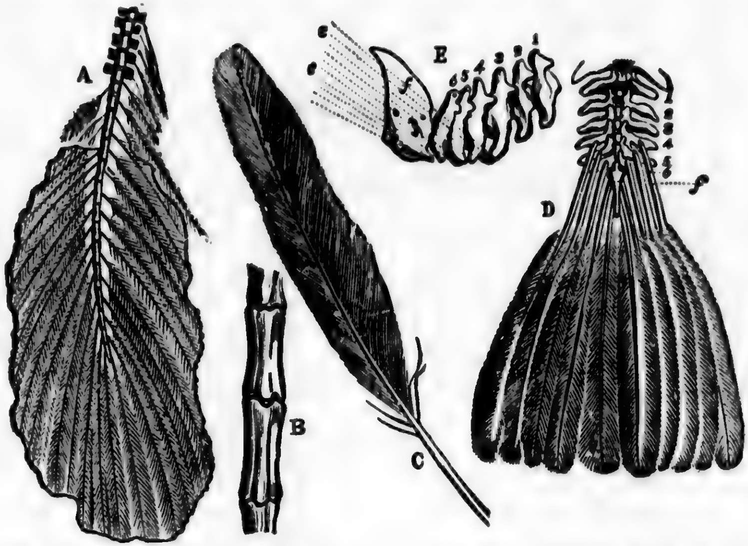


FIG. 150.—A, Tail of *Archæopteryx macrura.*—B, Two of the vertebræ of the tail, nat. size; C, A single feather, nat. size; D, Tail of a living vulture; E, Skeleton of the tail of the same, the dotted lines showing the attachment of the tail-feathers.

The Mammals of the Oolitic period are all small, and show no decided advance upon those of the Triassic rocks. They appear to have been for the most part insectivorous or flesh-eating Marsupials, allied to the living Banded Ant-eater (*Myrmecobius*) and Opossums (*Didelphys*).

CHAPTER XXII.

CRETACEOUS SERIES.

THE next series of rocks in ascending order is the great and important series of the *Cretaceous Rocks*, so called from the general occurrence in the system of chalk (Lat., *creta*, chalk). As developed in Britain and Europe generally, the following leading subdivisions may be recognized in the Cretaceous series (Fig. 151):

1. Wealden, 2. Lower Greensand or Neocomian,	Lower Cretaceous.
3. Gault, 4. Upper Greensand, 5. Chalk, 6. Mæstricht beds,	Upper Cretaceous.

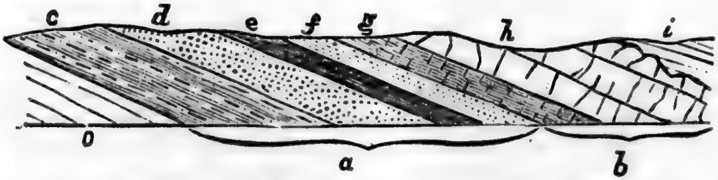


FIG. 151.—Generalized section of the Cretaceous rocks.—*a*, Lower Cretaceous rocks; *b*, Upper Cretaceous rocks; *c*, Wealden; *d*, Lower Greensand; *e*, Gault; *f*, Upper Greensand; *g*, Chalk-marl; *h*, White Chalk; *i*, Eocene rocks; *o*, Upper Oolites.

I. The *Wealden* formation, though of considerable importance, is a local group, and is confined to the southeast of England, France, and some other parts of Europe. Its name is derived from the *Weald*, a district comprising parts of Surrey, Sussex, and Kent, where it is largely developed. Its lower portion, for a thickness of from 500 to 1,000 feet, is arenaceous, and is known as the Hastings Sands. Its upper

portion, for a thickness of 150 to nearly 300 feet, is chiefly argillaceous, consisting of clays with sandy layers, and occasionally courses of limestone. The geological thickness of the Wealden formation is very great, and it is undoubtedly the delta of an ancient river, being composed almost wholly of fresh-water beds, with a few brackish-water and even marine strata, intercalated in the lower portion. Its geographical extent, though uncertain, owing to the enormous denudation to which it has been subjected, is nevertheless great, since it extends from Dorsetshire to France, and occurs also in North Germany. Still, even if it were continuous between all these points, it would not be larger than the delta of such a modern river as the Ganges. The river which produced the Wealden series must have flowed from an ancient continent occupying what is now the Atlantic Ocean; and the time occupied in the formation of the Wealden must have been very great, though we have, of course, no data by which we can accurately calculate its duration.

The fossils of the Wealden series are, naturally, mostly the remains of such animals as we know at the present day as inhabiting rivers. We have, namely, fresh-water mussels (*Unio*), river-snails (*Paludina*), and other fresh-water shells, with numerous little bivalved Crustaceans, and some fishes.

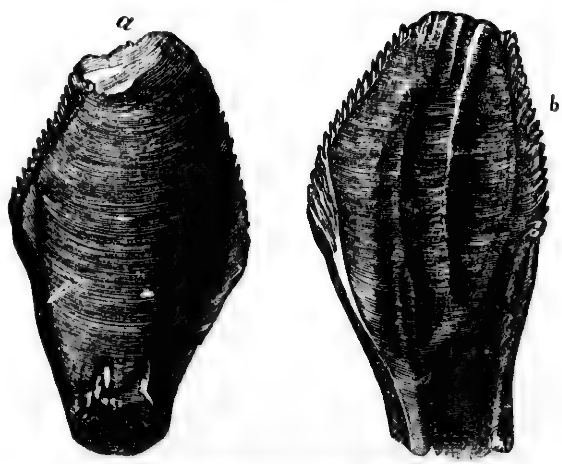


Fig. 152.—Teeth of *Iguanodon Mantelli*. Wealden.

Besides these, however—the natural fossils of such a fresh-water deposit—we find a number of remains of animals and

plants which were brought down by the current of the ancient stream. The animal remains consist of the bones of various gigantic reptiles belonging to the order *Deinosauria*, of *Plesiosaurus*, of the flying *Pterodactyles*, and of the cases of river-tortoises. Of the *Deinosauria*, the most remarkable is *Iguanodon*, which resembles the living *Iguanas*, especially in the form of its teeth (Fig. 152), but which is believed to have reached the tremendous length of from 50 to 60 feet. There is, also, good reason to suppose that *Iguanodon*, in spite of its vast bulk, walked, temporarily or permanently, upon two legs, like a bird.

Plant-remains occur abundantly in the Wealden, and agree with those of the Oolitic series and the Lower Greensand in consisting of Ferns, Conifers, and Cycads, without any Angiospermous Exogens.

II. The Wealden beds pass upward, often by insensible gradations, into the *Lower Greensand* (Fig. 151, *d*). The name Lower Greensand is not an appropriate one, for green sands only occur sparingly and occasionally, and are found in other formations. For this reason it has been proposed to substitute for Lower Greensand the name *Necocomian*, derived from the town of Neufchâtel—anciently called *Neocomum*—in Switzerland. If this name were adopted, as it ought to be, the Wealden beds would be called the Lower Neocomian.

The Lower Greensand or Neocomian of Britain has a thickness of about 850 feet, and consists of alternations of sands, sandstones, and clays, with occasional calcareous bands. The general color of the series is dark brown, sometimes red, and the sands are occasionally green, from the presence of silicate of iron.

The fossils of the Lower Greensand are purely marine, and among the most characteristic are the shells of *Cephalopods*.

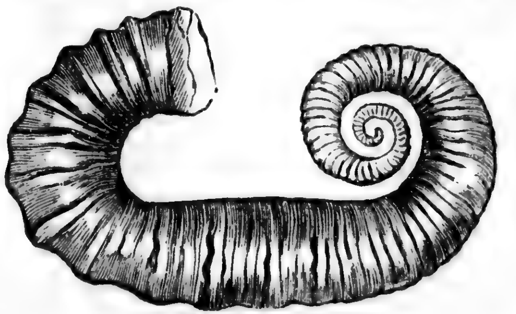


Fig. 153.—*Ancyloceras gigas.*

The genus *Nautilus* is represented by the *Nautilus plicatus* (Fig. 154), and there are a few *Ammonites* as well. Besides these, we have the allied genus *Ancyloceras* (Fig. 153), which is like an Ammonite partially unrolled, and having its larger end bent inward. There are also Bivalve Shell-fish, Belemnites, Sea-urchins, and Corals.

The most remarkable point, however, about the fossils of the Lower Cretaceous series is their marked divergence from the fossils of the Upper Cretaceous rocks. Of 280 species of fossils in the Lower Cretaceous series, only 51, or about 18 per cent., pass on into the Upper Cretaceous. This break in the life of the two periods is accompanied by a decided physical break as well, for the Gault is often, if not always, unconformably superimposed on the Lower Greensand. At the same time, the Lower and Upper Cretaceous groups form a closely-connected and inseparable series, as shown by a comparison of their fossils with those of the underlying Jurassic rocks and the overlying Tertiary beds. Thus, in Britain no marine fossil is known to be common to the marine beds of the Upper Oolites and the Lower Greensand; and of more than 500 species of fossils in the Upper Cretaceous rocks, almost every one died out before the formation of the lowest Tertiary strata, the only survivors being one Brachiopod and a few *Foraminifera*.

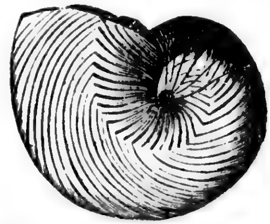


FIG. 154.—*Nautilus plicatus.*

III. The lowest member of the Upper Cretaceous series is a stiff, dark-gray, blue, or brown clay, often worked for brick-making, and known as the *Gault*, from a provincial English term. It occurs chiefly in the south-east of England, but can be traced through France to the flanks of the Alps and Bavaria. It never exceeds 100 feet in thickness; but it contains many fossils, usually in a state of beautiful preservation. Besides Bivalves and Univalves, the Gault contains many *Cephalopods*, such as Ammonites, Belemnites, *Ancyloceras* (Fig. 155), etc.

IV. The Gault is succeeded upward by the *Upper Greensand*, which varies in thickness from three up to 100 feet, and which derives its name from the occasional occurrence in it of green sands. These, however, are local and sometimes wanting, and the name "Upper Greensand" is to be regarded as a *name* and not a description. The group consists, in Britain, of sands and clays, sometimes with bands of calcareous grit

or siliceous limestone, and occasionally containing concretions of phosphate of lime, which are largely worked for agricultural purposes.

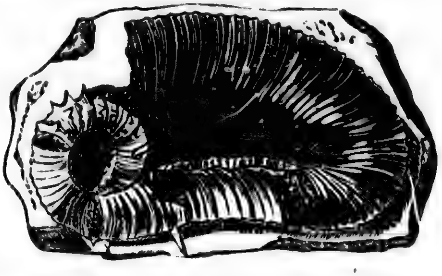


FIG. 155.—*Ancyloceras spinigerum.* Gault.

The fossils of the Upper Greensand are chiefly Sponges, Brachiopods, Echinoderms, Cephalopods, Reptiles, and Birds.

V. The top of the Upper Greensand becomes argillaceous, and passes up gradually into the base of the great formation known as the true *Chalk*, divided into the three subdivisions of the chalk-marl, white chalk without flints, and white chalk with flints. The first of these is simply argillaceous chalk, and passes up into a great mass of obscurely-stratified white chalk in which there are no flints. This, in turn, passes up into a great mass of white chalk, in which the stratification is marked by nodules of black flint arranged in layers. The thickness of these three subdivisions taken together is sometimes over 1,000 feet, and their geographical extent is very great. White Chalk, with its characteristic appearance, may be traced from the north of Ireland to the Crimea, a distance of about 1,140 geographical miles, and, in an opposite direction, from the south of Sweden to Bordeaux, a distance of about 840 geographical miles.

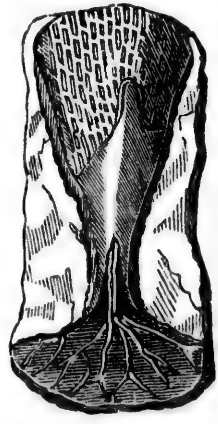


FIG. 156.—*Ventriculites radiatus*, a sponge of the White Chalk.

The fossils of the Chalk are extremely numerous, and consist chiefly of *Foraminifera*, Sponges, Echinoderms, Bivalves, and Cephalopods. As regards the first of these, almost the whole bulk of ordinary chalk is made up of the microscopic shells of *Foraminifera*, some of which are

specifically identical with forms now existing. Sponges are very numerous, some being mushroom-shaped, others branching, and others funnel-shaped. Of the last, a good example is to be found in *Ventriculites* (Fig. 156).

Of the *Mollusca*, the Chalk yields an enormous number of forms allied to the plant-like Sea-mosses and Sea-mats, with a good many Brachiopods. Bivalves are very numerous, and characteristic, the commonest being Scallops (*Pecten*) and Oysters (*Ostrea*). An exclusively Cretaceous genus of Bivalves is *Inoceramus* (Fig. 157). *Cephalopods* are very abundant,

Fig. 157. — *Inoceramus Lamarckii.* White Chalk.

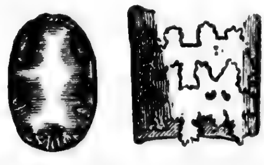


Fig. 158.—Portion of *Baculites Faujasii.*

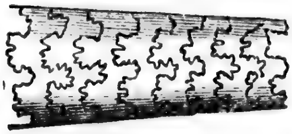


Fig. 159.—Portion of *Baculites anceps.*

and their forms are very varied. *Belemnites* and *Nautili* are present, as well as true *Ammonites*, but the most characteristic forms are *Baculites*, *Scaphites*, and *Turrilites*. These all agree with the *Ammonites* in having chambered shells, the partitions between the chambers of which are curiously folded (Fig. 159), but they differ in the shape of the shell. *Baculites* (Figs. 158, 159) have a straight, staff-shaped shell, resembling an *Orthoceras* in shape, but differing in the form of the partitions. The shell of the *Turrilite*, again, is coiled into a spiral, the convolutions of which do not lie in one plane (as in the *Ammonite*), but are drawn out into a cone or turret (Fig. 160). The *Scaphite*, lastly, resembles an *Ammonite*, the larger extremity of which has been unrolled, and is finally bent inward toward the smaller, coiled-up portion (Fig. 161).

Fig. 160. — *Turrilites costatus.*

Of all the Chalk-fossils, however, none are more abundant or more characteristic than Sea-urchins, which occur in very varied forms and in a state of beautiful preservation. Two very characteristic species are figured below (Figs. 162, 163). Remains of Fishes are tolerably abundant in the White Chalk, and here for the first time we meet with Bony Fishes, with flexible horny scales, resembling the great majority of living Fishes. There are, however, also Shark-like Fishes allied to the Port-Jackson Shark (*Cestracion*), and numerous true Sharks.

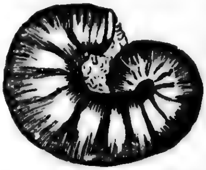


FIG. 161. — *Scaphites æqualis.*

As the Chalk is certainly a deep-sea deposit, we naturally find in it no remains of strictly terrestrial animals or of land-plants. Remains, however, of Turtles and *Pterodactyles* occur, and the latter appear now to have finally died out, as they have not been met with in any later deposit.

VI. In Britain there occur no beds containing Chalk-fossils, or in any way referable to the Cretaceous period, above the true White Chalk with flints. On the banks of the Maes, however, near Maestricht, in Holland, there occurs

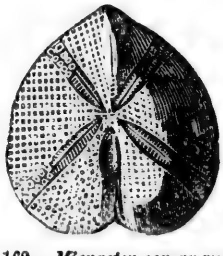


FIG. 162.—*Micraster cor-anguinum.*

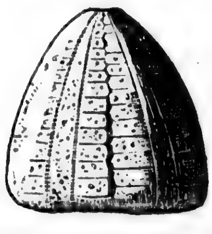


FIG. 163.—*Galerites albogalerus.*

a series of yellowish limestones, of about 100 feet in thickness, and undoubtedly superior to the White Chalk. These *Maestricht beds* contain a remarkable series of fossils, the characters of which are partly Cretaceous, and partly Tertiary. Thus, with the characteristic Chalk-fossils, *Belemnites*, *Baculites*, Sea-urchins, etc., are numerous Univalve Mollusks, such as Cowries and Volutes, which are otherwise exclusively Tertiary or Recent. Another celebrated Maestricht fossil is the skull of a gigantic marine Lizard, which has been described under the name of *Mosasaurus* (Fig. 164).

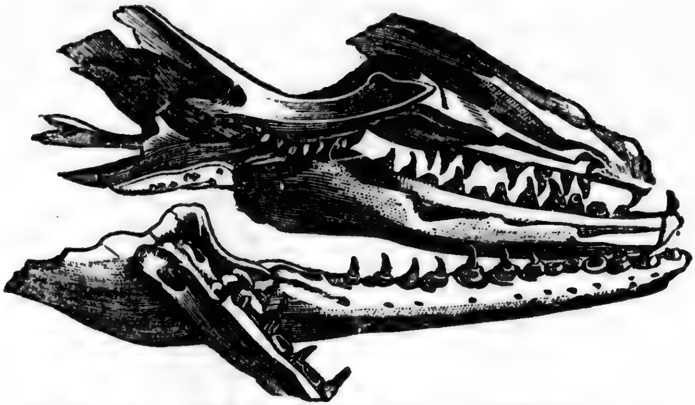


FIG. 164.—Skull of *Mosasaurus Camperi*.—Original over three feet in length.

Holding a similar position to the Maestricht beds, and showing a similar intermixture of Cretaceous forms with later types, are certain beds which occur in the island of Seeland, in Denmark, and which are known as the *Faxöe Limestone*.

CHALK OF THE SOUTH OF EUROPE.—The great Chalk formation of the south-west of England is continuous with a similar series in the north of France, the two forming part of one continuous mass, in which the Straits of Dover form merely a shallow furrow. South of the Parisian basin, in the south of France, there are again Cretaceous rocks, but the series here differs a good deal both in mineral characters and fossils from the Chalk of the north of Europe. *Ammonites*, for instance, are very rare, and *Turrilites*, *Scaphites*, and *Belemnites*, appear to be wanting. The most characteristic member of the Cretaceous series of the south of Europe consists of certain compact marbles, known as *Hippurite limestones*. This name is derived from the abundance in these beds of a very peculiar family of Bivalve Mollusks known as *Hippurites* (Fig. 165). All the members of this family were attached and lived associated in beds, like Oysters. The two valves of the shell are always altogether unlike in sculpturing, in appearance, and in shape; and the cast of the interior of the shell is often extremely unlike the outer surface of the shell (compare *a* and *d*, Fig. 165). About a hundred different species of the family *Hippuritidæ* are known, all of which, so far as is known, are exclusively Cretaceous, occurring in Britain, Southern Europe, the West Indies, Algeria, and the East.

CRETACEOUS ROCKS OF NORTH AMERICA. — The Lower

Cretaceous rocks are represented not at all, or very feebly, in North America; but there is a very extensive development of rocks of Upper Cretaceous age in the United States. "The

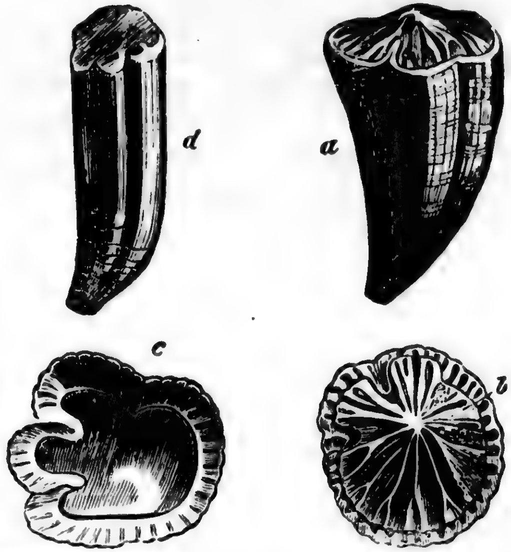


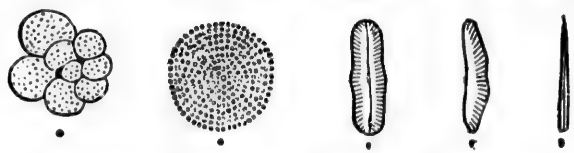
FIG. 165.—*Hippurites organisans.*—*a*, A separate shell; *d*, Cast of the interior of the same; *c*, Upper end of the lower conical valve; *b*, Upper side of the upper valve.

Cretaceous rocks occur—1. At intervals along the *Atlantic border*, south of New York, from New Jersey to South Carolina; 2. Extensively over the States along the *Gulf border*, and 3. Through a large part of the *Western interior region*, over the slopes of the Rocky Mountains, from Texas northward, to the head-waters of the Missouri on the east of the summit of the chain, and far into the Colorado region on the west. Still farther north-west in British America, they appear on the Saskatchewan and Assiniboine, and also on the Arctic Sea, near the mouth of the Mackenzie" (Dana, "Manual of Geology"). The rocks of these areas consist chiefly of sands, marls, clays, and limestones; but it is to be remembered that there is no white *Chalk*. Green sands are often present, as in New Jersey, where they are called "marls," and are largely worked for agricultural purposes, their fertilizing properties being due to the presence of a small percentage of phosphate of lime. The *fossils* of the Cretaceous rocks of North America

agree generally with those of the Upper Cretaceous rocks of Europe, and some of them will be spoken of in treating of the life of the period.

Origin of Chalk and Flints.—As regards the origin of the great masses of soft pulverulent White Chalk, it is now generally admitted that it is a deep-water deposit, and is formed chiefly of the shells of those minute *Protozoa* which are termed *Foraminifera*. Researches in the deep Atlantic have shown that there is now in process of formation at great depths in this ocean a deposit of white, chalky mud, which is known as "ooze," and which, if consolidated, would form a chalk-like rock. This ooze is composed almost entirely of the microscopical shells of *Foraminifera*, especially of the genus *Globigerina* (Fig. 166). Besides these, are the flinty cases of

Fig. 166. Fig. 167. Fig. 168. Fig. 169. Fig. 170.



Organic bodies in the ooze of the Atlantic bed at great depths.
Fig. 166.—*Globigerina bulloides*, a *Foraminifer*.
Figs. 167–169.— Siliceous plants (Diatoms).
Fig. 170.—Spicule of a siliceous sponge.

certain of the lower plants (*Diatoms*, Figs. 167–169), also of microscopic size; and, lastly, there are the needle-like spicules of flint which are part of the skeleton of the siliceous sponges (Fig. 170).

Chalk, similarly, has been shown to consist in great part of the shells of *Foraminifera*, some of which are actually identical with existing species; so that there can no longer be any doubt as to the chalk having originated as a deep-sea deposit, much as we now see in the Atlantic ooze. Not only so, but the ooze of the deep Atlantic is further found to be peopled with higher animals greatly resembling those now found fossil in the Chalk, similar conditions of life favoring the occurrence of representative forms. We do not, it is true, meet with the characteristic Cephalopods of the Chalk; but we find Sea-urchins, Crinoids, and siliceous Sponges, sufficient to establish a decided resemblance between two deposits so widely removed in time.

As regards the origin of flints in Chalk, it is now generally

admitted that these must be also ascribed to organic agencies. The water of the sea contains a minute proportion of silica in solution, and this is withdrawn by the living agency of animals or plants to form their shells or skeletons. Thus, certain of the lower plants (*Diatoms*) secrete a siliceous shell (Figs. 167-169), and these abound in the waters of the ocean, lakes, and rivers. There are also certain animalcules, nearly allied to the *Foraminifera*, which secrete a flinty shell; and many sponges produce a flinty skeleton. Remains of all these living beings may be detected in sections of flint under the microscope, and similar bodies have now been found in the nodules of hornstone (impure flint), which are found in many of the older rocks, from the Devonian upward. We may conclude, then, that flints are chiefly due to the exertions of animals and plants. Their occurrence in layers seems to be in some measure connected with "the periodic growth of large crops of sponges" (Owen).

Life of the Cretaceous Period.—As regards the vegetation of the Cretaceous period, we have to mark a great advance over the plants of the preceding periods. The plants of the Lower Cretaceous rocks agree with those of the earlier Oolitic period, in consisting chiefly of Ferns, Cycads, and Conifers, without any Angiospermous Exogens. In the Upper Cretaceous rocks, however, we meet for the first time with an abundance of forms allied to our ordinary trees and shrubs, and belonging to the class of the Angiospermous Exogens. Not only is this the case, but we meet with many familiar genera, such as the Oak, Willow, Walnut, Fig, Beech, Poplar, etc. It is singular, therefore, to reflect that trees, differing little from those of our own forests, should have coexisted with the *Ammonites* and *Belemnites*, and other extinct forms of marine life which characterize the Upper Cretaceous period. Here, also, we meet for the first time with true *Palms*.

The *Protozoa* are represented by numerous *Foraminifera*, which are found chiefly in the Chalk, but also in other beds, and by an abundance of Sponges of various forms. The *Cœlenterates* are represented by Corals; the *Echinodermata* are represented by a profusion of Sea-urchins; but the *Crinoids*, so characteristic of the older periods, are now reduced to a few forms, nearly resembling living species. *Crustaceans* are not common, the most abundant being little bivalved forms like the living Water-fleas; but there are also a few Barnacles, and some of the higher stalk-eyed species, like Crabs and Lobsters. The *Mollusca* are represented by an enormous number

of forms, belonging to all the great subdivisions of the class. The *Brachiopods* are proportionately much reduced in numbers, and their forms approximate more closely to living species. The *Bivalves* are represented by numerous types, of which some are of existing genera, such as the Scallop and Oyster; while others are exclusively Cretaceous, such as *Inoceramus* (Fig. 157), and the entire family of the *Hippuritidæ* (Fig. 165). Univalves are pretty abundant, but the greatest development of the Molluscan sub-kingdom is in the class *Cephalopoda*, which is represented by a great number of complex and beautiful forms. *Ammonites* and *Belemnites* continue their life from the uppermost beds of the Trias, but die out finally here. The true *Ammonites*, however, are to a great extent superseded by allied forms, such as the *Baculite* (Fig. 159), the *Turrilite* (Fig. 160), and the *Scaphite* (Fig. 161). All these, also, disappear with the close of the Cretaceous period.

The Vertebrate sub-kingdom is represented by Fishes, Reptiles, and Birds, no Mammals having hitherto been detected. In this period we meet for the first time with representatives of the Bony Fishes, with thin, flexible, horny scales, such as now predominate in existing waters. Here, also, we meet with true Sharks, many of which were of large size. The older groups of the *Ganoids* and the fishes allied to the Port-Jackson Shark (*Cestracionts*) are, however, still represented; and, indeed, both groups have survived to the present day, though reduced in numbers. Reptiles are very numerous, and are represented by many orders. The *Deinosauria*, which commenced in the Oolitic period, are represented by the gigantic *Iguanodon* of the Wealden, the *Hadrosaurus* of North America, and other forms, but died out during this epoch. The marine *Ichthyosaurus* and *Plesiosaurus*, with the flying *Pterodactyles*, which also commenced in the Jurassic period, are represented in the Cretaceous epoch, and also die out at its close. The Lizards are represented by the *Mosasaurus* of Europe, a gigantic marine reptile, by an equally gigantic and nearly allied form from New Jersey, and by related species of smaller size. Turtles are represented by several forms, and there are also true Crocodiles in the Cretaceous beds of New Jersey.

KAINOZOIC EPOCH.

CHAPTER XXIII.

EOCENE FORMATION.

BEFORE commencing the study of the subdivisions of the Kainozoic series, there are some general considerations to be noted. In the first place, there is a complete and entire physical break between the rocks of the Mesozoic and Kainozoic periods. In no instance are Tertiary strata to be found resting conformably upon any Secondary rock. The Chalk has invariably suffered much erosion and denudation before the lowest Tertiary strata were deposited upon it. This is shown by the fact that the actually eroded surface of the Chalk can often be seen, or, failing this, that we can point to the presence of the chalk-flints in the Tertiary strata. This last, of course, affords unquestionable proof that the Chalk must have been subjected to enormous denudation prior to the formation of the Tertiary beds, all the chalk itself having been removed, and nothing left but the flints, while these are all rolled and rounded.

In the second place, there is a complete break in the *life* of the Mesozoic and Kainozoic periods. With the exception of a few *Foraminifera*, and one *Brachiopod* (the latter doubtful), no Cretaceous *species* is known to have survived the Cretaceous period; while several characteristic *families*, such as the *Ammonitidæ* and *Hippuritidæ*, died out entirely with the close of the Cretaceous rocks. In the Tertiary rocks, on the other hand, not only are all the animals and plants more or less like existing types, but we meet with a constantly increasing number of *living species* as we pass from the bottom of the Kainozoic series to the top. Upon this last fact, as we

shall see, is founded the modern classification of the Kainozoic rocks, propounded by Sir Charles Lyell.

It follows from the constant want of conformity between the Cretaceous and Tertiary rocks, and still more from the entire difference in life, that the Cretaceous and Tertiary periods are separated by an enormous lapse of unrepresented time. How long this interval may have been, we have no means of judging exactly, but it very possibly was as long as the whole Kainozoic epoch itself. Some day we shall doubtless find, at some part of the earth's surface, strata which were deposited during this period, and which will contain fossils intermediate in character between the organic remains which respectively characterize the Secondary and Tertiary periods. At present, we have only slight traces of such deposits, such, for instance, as the Maestricht beds.

Classification of the Tertiary Rocks.—The classification of the Tertiary rocks is a matter of unusual difficulty, in consequence of their occurring in disconnected basins, forming a series of detached areas, which hold no relations of superposition to one another. The order, therefore, of the Tertiaries in point of time can only be determined by an appeal to fossils; and in such determination Sir Charles Lyell proposed to take as the basis of classification the *proportion of living or existing species which occur in each stratum or group of strata.* Acting upon this principle, Sir Charles Lyell divided the Tertiary series into four groups:

I. The *Eocene* formation (Gr. *eos*, dawn; *kainos*, new), containing the smallest proportion of existing species, and being, therefore, the oldest division. In this classification, only the *Mollusca* are taken into account; and it was found that of these about three and a half per cent. were identical with existing species.

II. The *Miocene* formation (Gr. *meion*, less; *kainos*, new), with more recent species than the Eocene, but *less* than the succeeding formation, and less than one half the total number in the formation. As before, only the *Mollusca* are taken into account, and about 17 per cent. of these agree with existing species.

III. The *Pliocene* formation (Gr. *pleion*, more; *kainos*, new), with *more* than half the species of shells identical with existing species; the proportion of these varying from 35 to 50 per cent. in the lower beds of this division, up to 90 or 95 per cent. in its higher portion.

IV. The *Post-Tertiary Formations*, in which *all the shells*

belong to existing species. This, in turn, is divided into two minor groups—the *Post-Pliocene* and *Recent Formations.* In the *Post-Pliocene* formations, while all the *Mollusca* belong to existing species, most of the *Mammals* belong to extinct species. In the *Recent* period, the quadrupeds, as well as the shells, belong to living species.

The above, with some modifications, was the original classification proposed by Sir Charles Lyell for the Tertiary rocks, and now universally accepted. More recent researches, it is true, have somewhat altered the proportions of existing species to extinct, as stated above. The general principle, however, of an increase in the number of living species still holds good; and this is as yet the only satisfactory basis upon which it has been proposed to arrange the Tertiary deposits.

EOCENE FORMATION.

The Eocene rocks are the lowest of the Tertiary series, and comprise all those Tertiary deposits in which there is only a small proportion of existing *Mollusca*—from three and a half to five per cent. The Eocene rocks occur in several basins in Britain, France, the Netherlands, and other parts of Europe, and in the United States. The subdivisions which have been established are extremely numerous, and it is often impossible to parallel those of one basin with those of another. It will be sufficient, therefore, to accept the division of the Eocene formation into three great groups—Lower, Middle, and Upper Eocene—and to consider some of the more important beds comprised under these heads in Europe and in North America (Fig. 171).

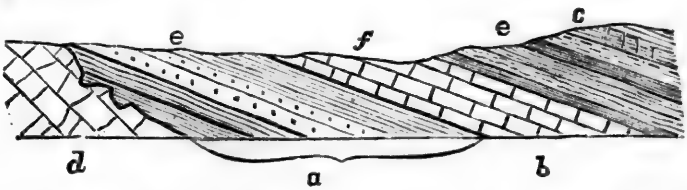


FIG. 171.—Generalized section of the Eocene rocks.—*a*, Lower Eocene; *b*, Middle Eocene; *c*, Upper Eocene; *d*, Chalk; *e*, London Clay; *f*, Nummulitic Limestone.

I. LOWER EOCENE.—The Lower Eocene rocks of Britain consist of sands, mottled clays, lignites, and gravels, surmounted by a great mass of dark-brown or blue clay, which has a thickness of from 200 to 500 feet, and is known as the

London Clay. The London Clay is a marine deposit, and contains many marine fossils, with the remains of terrestrial animals and plants. All the remains indicate a high temperature of the sea and tropical or sub-tropical conditions. The *Mollusca* belong chiefly to well-known tropical genera, such as Volutes, Cones, and Cowries (Fig. 172), and there are also several species of *Nautilus* and other *Cephalopods.* Crustaceans allied to the living Crabs and Lobsters are likewise abundant. Fish are numerous, and are mostly related to the living Sharks, but there are also remains of Sword-fishes and Saw-fishes. Turtles, Sea-snakes (*Palæophis*), and Crocodiles, have been detected; and the remains of Birds and Quadrupeds also occur. Of the latter, the most important are *Hyracotherium*, belonging to the Hog-family, and *Coryphodon*, allied to, but larger than, the living Tapirs.

FIG. 172.—*Voluta nodosa.* (London Clay.)

In North America, Lower Eocene rocks are extensively developed at Claiborne, Alabama, and consist of clays, lignites, marls, and impure limestones. The fossils of the Claiborne beds are very numerous, and belong to the same groups as those of the London Clay, except that Mammals appear to be wanting. The lignites (imperfect coals) contain numerous plant-remains.

II. MIDDLE EOCENE.—The Middle Eocene of Britain consists chiefly of sands, clays, and gravels. In France, the Middle Eocene consists chiefly of a compact limestone (the so-called "Calcaire Grossier"), which contains an extraordinary number of fossils. Among these are more than 130 species of a single genus of Univalve Mollusks (*Cerithium*), almost all the living forms of which inhabit estuaries, where the water is brackish.

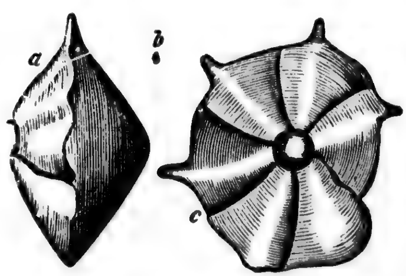


FIG. 173.—*Calcarina rarispina.* *b*, Nat. size; *a*, *c*, Same magnified.

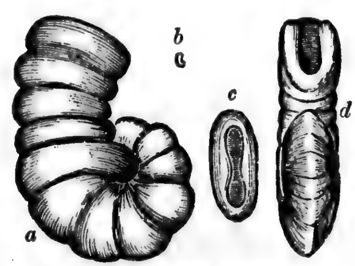


FIG. 174.—*Spirolina stenostoma.* *b*, Natural size; *a*, *c*, *d*, Same magnified.

Foraminifera are also wonderfully abundant, whole beds of limestone being almost composed of their shells. Some of the more characteristic species are figured above (Figs. 173, 174).

More important than the above minute forms of the *Foraminifera* are certain large coin-shaped species called *Nummulites* (Lat. *nummus*, a coin), which occur in the Eocene beds of almost all parts of the world. The *Nummulites* (Fig. 175) are so abundant in one of the Middle Eocene rocks, that

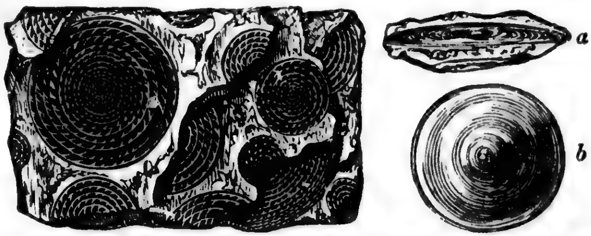


FIG. 175.—*Nummulites Puschi.*—*a*, External surface of one of the Nummulites, of which longitudinal sections are seen in the limestone; *b*, Transverse section of the same.

it has been called the "Nummulitic Limestone." This formation attains a thickness of sometimes thousands of feet, and is largely developed in the Alps. It supplied the stone of which the Pyramids were built, and it has been traced through India to the frontiers of China. It is worthy of notice in this connection that the Eocene rocks of the Alps have not the comparatively soft, incoherent, and unaltered character of the Tertiary rocks in general. They rival the older Palæozoic rocks in thickness, and are as much contorted, faulted, indurated, and cleaved; while they rise in many instances to very lofty elevations.

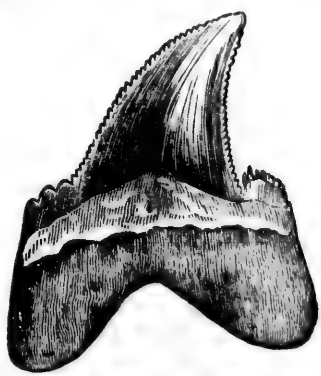


FIG. 176.—Tooth of *Carcharodon heterodon*.

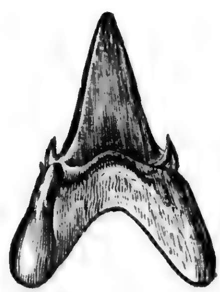


FIG. 177.—Tooth of *Otodus obliquus*.

The Middle Eocene rocks of Britain, besides *Nummulites*, contain many univalve and bivalve Mollusks, a large marine serpent of the Constricting family (*Palæophis*), a Crocodile, an' numerous Fishes. Among the remains of the last of these are the pavement-like teeth of huge Rays (*Myliobatis*), and the trenchant teeth of large Sharks (*Carcharodon*, *Otodus*, etc., Figs. 176, 177).

The Middle Eocene group is represented in North America by lignitic clays and marls which occur at Jackson, Mississippi. Among the more remarkable fossils of the Jackson beds are the teeth and bones of a gigantic Mammal belonging to the order of the Whales, but differing from all existing forms in having molar teeth with double roots (Fig. 178). It forms the genus *Zeuglodon*, and attained a length of 70 feet.

Zeuglodon cetoides.

FIG. 178.—Molar tooth, nat. size. FIG. 179.—Vertebra, reduced.

III. UPPER EOCENE.—The Upper Eocene is poorly represented in Britain by alternations of fresh-water, brackish-water, and purely marine beds, consisting of clays, sands, marls, and limestones. The fresh-water beds are characterized by the occurrence of Pond-snails, River-snails, and other shells peculiar to fresh waters, along with Land-snails. There are also fresh-water Tortoises, Snakes, Crocodiles, and Fishes, one of the latter being closely allied to the Gar-pike of the United States. Mammals are numerous and belong to several genera, the two most important being *Anoplotherium*, a hoofed quadruped forming a kind of link between the Swine and the true Ruminants, and *Hyænodon*, a large carnivorous animal allied to the living Hyænas. Here, also, we have the genus *Palæotherium*, which is represented by several species allied to the living Tapirs (Fig. 180).

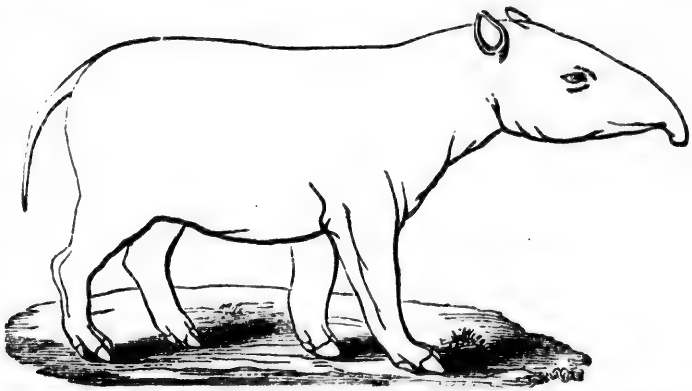


FIG. 180.—Outline of *Palæotherium magnum*, as restored by Cuvier. Upper Eocene.

The most important member of the Upper Eocene of France is the so-called "Gypseous series of Montmartre," named from the hill of Montmartre in the vicinity of Paris. This series consists of three masses of granular crystalline gypsum, largely quarried for plaster of Paris, with intervening laminated marls. The most remarkable fossils of this series are Mammals, of which about fifty species are known. Four-fifths of these are hoofed quadrupeds, more or less closely allied to the Rhinoceros, Tapirs, and Swine of the present day, the two most important genera being *Anoplotherium* and *Palæotherium*. There are also Marsupials, Bats, Rodents, and Carnivores, all belonging to extinct species.

Rocks of Upper Eocene age occur in North America at Vicksburg, Mississippi, and consist of lignites, clays, marls, and limestones. On the White River they are about 1,000 feet thick, and consist of clays, sandstones, and limestones, of fresh-water origin. Among their most remarkable fossils are the remains of Mammals, of which about forty species have been already determined. Among these we have two *Rhinoceroses*, several *Carnivorous* animals, some small animals allied to the *Mice*, and a number of herbivorous animals related to the *Tapirs*, *Peccary*, *Camel*, etc.

LIFE OF THE EOCENE PERIOD.—Little need be added here as to the life of the Eocene period, fossils being so abundant as to render it impossible to do more than indicate some general considerations. Upon the whole, the plants and animals of the Eocene period closely resemble those now in existence upon the globe; not, however, necessarily in the exact

localities in which they are now found. Thus, the modern representatives of the plants and animals of the Eocene rocks of Europe are not to be found in Europe itself, but in some tropical or sub-tropical region. The climatic conditions of Europe in the Eocene period were very different to those at present subsisting, and the animals and plants were correspondingly different. Still, there are few Eocene fossils which have not their modern representatives in warm countries.

Foraminifera are peculiarly abundant in the Eocene seas, and sometimes attained a size rarely equalled by existing forms, Nummulites being often as much as three inches in circumference. *Corals* are not abundant, but more closely resemble living types. *Brachiopods* are much reduced in numbers, both individually and as regards the types represented. *Univalve* and *Bivalve Mollusks* are exceedingly abundant, and most recent *genera* are represented, though less than five per cent. only are identifiable with existing species. The *Ammonites*, *Turrilites*, *Baculites*, *Belemnites*, etc., of the Cretaceous rocks have now disappeared, and the *Cephalopoda* are represented mainly by *Nautili.* Fishes are abundant, the leading types being true Sharks, some of which must have reached a perfectly tremendous length. The large and wonderfully-modified Reptiles of the Mesozoic series are no longer in existence, but their place is taken by other forms agreeing more closely with existing types. Birds are tolerably abundant, and all the living orders of the class find some ancient representative here. Lastly, Mammals show an extraordinary advance, both in point of numbers and development, as compared with the Mesozoic period. In the latter epoch we have no certain evidence of any quadrupeds higher in the scale than *Marsupials*, allied to living Kangaroos, Opossums, etc. In the Eocene Tertiary, however, we meet with representatives of the greater number of the chief mammalian orders. Besides Marsupials, we have Eocene examples of the orders *Sirenia* (Dugongs), *Cetacea* (Whales), *Ungulata* (Hoofed Quadrupeds), *Carnivora* (Lion, Tiger, Hyæna, etc.), *Rodentia* (Mouse, Beaver, etc.), *Insectivora* (Mole, Hedgehog, etc.), and *Cheiroptera* (Bats). The orders of the *Proboscidea* (Elephants), and *Quadrumana* (Monkeys), are not known to be represented in this period.

CHAPTER XXIV.

MIOCENE FORMATION.

The *Miocene* formations comprise those Tertiary deposits which contain less than about 35 per cent. of existing species of *Mollusca*, and more than five per cent., or those deposits in which the proportion of living shells is less than of extinct species. The *Miocene* formations are divisible in Europe into a *Lower Miocene* and *Upper Miocene* group.

I. Lower Miocene.—The Miocene formations are very poorly represented in Britain, their leading development being at Bovey Tracy, in Devonshire, where there occur sands, clays, and beds of lignite or woody coal. These strata contain numerous plants, among which are Vines, Figs, the Cinnamon-tree, Palms, and a number of *Coniferæ*. Of the Conifers, the most abundant is a gigantic Pine (*Sequoia Couttsiæ*), which is most nearly allied to the huge *Sequoia gigantea* of California. Other plant-bearing strata in the Hebrides, on the west coast of Scotland, have been referred to the Miocene age.

In France, the Lower Miocene is represented in Auvergne, Cantal, and Velay, by a great thickness of nearly horizontal strata of sand, sandstone, clays, marls, and limestones, all of fresh-water origin. Other Miocene deposits occur in Austria, Germany, Switzerland, and the Siwalik hills in India, some of which will be further alluded to hereafter.

II. Upper Miocene.—The typical European deposits of Upper Miocene age occur in the valley of the Loire, in France, and are known as the "Faluns," a provincial term given to shelly sands employed to spread upon soils which are deficient in lime. The Faluns occur in scattered patches, which are rarely more than 50 feet in thickness, and consist of sands and marls. The fossils are chiefly marine, but there occur also land and fresh-water shells, and the remains of numerous

Mammals. Some of these last, such as the Walrus, Manatee, and Dolphin, are aquatic; while others are terrestrial, such as the *Hippopotamus*, *Rhinoceros*, *Mastodon*, and *Deinotherium* (Fig. 181). The *Mastodons* resembled the Elephants in most respects, but differ in the shape of the molar teeth. The *Deinotherium* was a gigantic *Proboscidean*, allied to the Elephants, but differing in possessing greatly-developed incisor teeth in

FIG. 181.—Skull of *Deinotherium giganteum*.

FIG. 182.—*Voluta Lamberti*. Faluns.

the lower jaw, which formed long, curved tusks, bent downward in a most singular manner. The shells of the Faluns belong to more than 300 species, of which only 45 are common to the Pliocene. They indicate a tropical climate, and consist chiefly of Cones, Volutes (Fig. 182), Cowries, and other well-known tropical genera. About 25 per cent. of the shells belong to existing species.

In Switzerland, between the Alps and the Jura, there occurs a great series of Miocene deposits, known collectively as the "Molasse," from the soft nature of a greenish sandstone, which constitutes one of its chief members. It attains a thickness of many thousands of feet, and rises into lofty mountains, some of which—as the Rigi—are more than 6,000 feet in height. The middle portion of the Molasse is of marine origin, and is shown by its fossils to be of the age of the Faluns; but the lower and upper portions of the formation are mainly or entirely of fresh-water origin. The Lower Molasse

(of Lower Miocene age) has yielded about 500 species of plants, mostly of tropical or sub-tropical forms. The Upper Molasse has yielded about the same number of plants, with about 900 species of Insects, such as wood-eating Beetles, Water-beetles, White Ants, Dragon-flies, etc. Of the characters of the plants something will be said in speaking of the vegetation of the Miocene period.

Miocene of North America.—Miocene deposits are found in the United States in New Jersey, Maryland, Virginia, California, Oregon, etc., and they attain sometimes a thickness of 1,500 feet. They consist chiefly of clays, sands, and sandstones; and in Virginia there is a bed of what is wrongly called "Infusorial Earth," which attains a thickness of many feet, and consists almost wholly of the siliceous cases of certain low forms of plants (Diatoms). The strata of the White River, with remains of numerous Mammals, formerly spoken of as Upper Eocene, are sometimes referred to the Miocene formation. The fossils of the American Miocene are chiefly *Mollusks* (of which 15 to 30 per cent. are living species), Sharks, Whales, Dolphins, and Seals.

Life of the Miocene Period.—As regards the animals of the Miocene, only the Mollusks and Mammals need any special notice. The *Mollusca* of the Miocene deposits (when these are marine) are referable to genera now in existence, but, for the most part, proper to warm climates. The percentage of living forms varies from 15 to 30 per cent. In the European Miocene, however, though shells of existing species are present, these do not belong to species now found in European seas. Very few of the now existing European shells are found in any Tertiary deposit older than the Pliocene. In America, however, shells now extinct, such as *Fusus quadricostatus* (Fig. 184) are found side by side in the Miocene Tertiaries with shells which still exist in American waters, such as *Fulgur canaliculatus* (Fig. 183).

The Mammals of the Miocene period are very numerous, and show an advance upon those of the Eocene period. The entire order of the *Proboscidea*, comprising only the recent Elephants, appears to have first come into existence in the Miocene period, where it is represented not only by true Elephants, but by the nearly-allied *Mastodons*, and the singular *Deinotherium*. The order *Quadrumana*, comprising the Apes and the Monkeys, likewise appears to date its existence from the Miocene period, when it is represented by forms allied to the Monkeys of the Old World. True Deer first make their appearance

in the Miocene, with Giraffes and Antelopes, some of the last of gigantic size and furnished with four horns. The *Edentates* (such as the modern Sloths, Armadillos, and Ant-eaters) are represented by a gigantic form somewhat allied to the Scaly Ant-eaters or Pangolins of the Old World. Lastly, the great order of the *Carnivora* was represented in two of its leading divisions by the bear-like *Amphicyon* and the great sabre-toothed tiger, *Machairodus.*

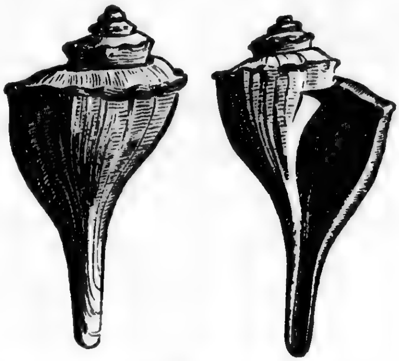


Fig. 183.—*Fulgur canaliculatus.* Maryland, Miocene and recent.

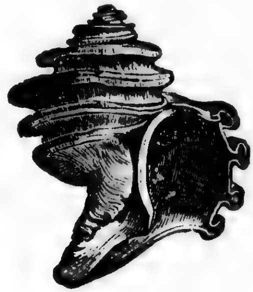


Fig. 184.—*Fusus quadricostatus.* Maryland, Miocene.

Vegetation of the Miocene Period.—Our chief sources of information as to the vegetation of the Miocene period are derived from the brown coals of Germany and Austria, the Lower and Upper Molasse of Switzerland, and the Miocene beds of Greenland. The brown coals, or lignites, of Germany and Austria are simply vegetable matter in process of conversion into ordinary coal, but still retaining a good deal of its original structure. From marlstone associated with these brown coals at Radaboj, in Croatia, have been obtained more than 200 species of plants, most of which indicate tropical conditions. Among these is the Sabal (Fig. 187), a genus of Palms which is now found in America. Accompanying these plant-remains are numerous insects, among which are Termites, or White Ants, Dragon-flies, Grasshoppers, and even Butterflies (Fig. 185).

The plants of the Lower Miocene of Switzerland are also mostly of a tropical character, but include several American forms, such as a Tulip-tree (*Liriodendron*) and a Cypress (*Taxodium*). Among the more remarkable forms from these

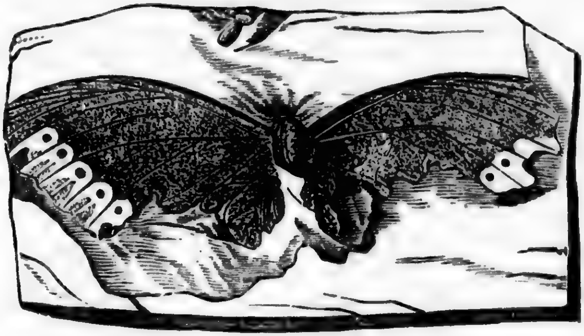


FIG. 185.—*Vanessa Pluto*, nat. size. Lower Miocene, Radaboj.

beds may be mentioned numerous tropical ferns, two species of Cinnamon, and a Fan-palm (*Chamærops*, Fig. 186).

The plant-remains of the Upper Molasse of Switzerland indicate an extraordinarily rank and luxuriant vegetation, composed mainly of tropical forms. Among the commoner plants

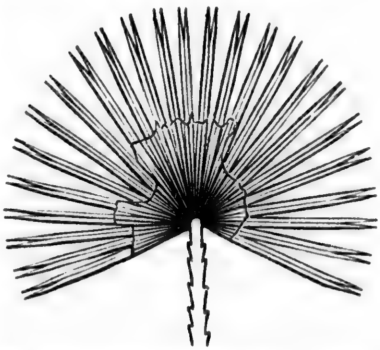


FIG. 186. — *Chamærops Helvetica.* Lower Miocene.

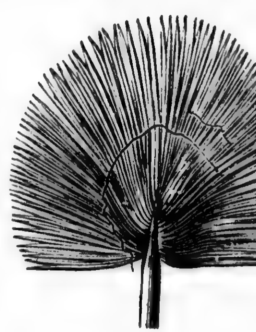


FIG. 187.—*Sabal major.* Lower Miocene, France.

of this formation are many species of Maple (*Acer*), Plane-trees (*Platanus*, Fig. 188), Cinnamon-trees (Fig. 189), with other members of the Laurel order, numerous species of Sarsaparilla (*Smilax*), with Palms, Cypresses, etc.

In Greenland, as well as in other parts of the Arctic regions, Miocene strata have been discovered which have yielded a great number of plants, many of which are identical with species found in the European Miocene. Among these plants are many

trees, such as Conifers, Beeches, Oaks, Maples, Walnuts, Magnolias, etc., with numerous shrubs, ferns, and other smaller plants.

FIG. 188.—*Platanus aceroides.*—*a*, Leaf; *b*, The core of a bundle of pericarps; *c*, Single fruit or pericarp, natural size. Upper Miocene.

FIG. 189.—*Cinnamomum polymorphum.*—*a*, Leaf; *b*, Flower. Upper Miocene.

Taking the Miocene flora as a whole, Dr. Heer concludes from his study of about 3,000 plants contained in the European Miocene alone, that the Miocene plants indicate tropical or sub-tropical conditions, but that there is a striking intermixture of forms which are at present found in countries widely removed from one another. It is impossible to state with certainty how many of the Miocene plants belong to existing species, but it appears that the larger number are extinct. According to Heer, the American types of plants are most largely represented in the Miocene flora, next those of Europe and Asia, next those of Africa, and lastly those of Australia. Upon the whole, however, the Miocene flora of Europe is mostly nearly allied to the plants which we now find inhabiting the warmer parts of the United States; and this has led to the suggestion that in Miocene times the Atlantic Ocean was dry land, and that a migration of American plants to Europe was thus permitted. This view is borne out by the fact that the Miocene plants of Europe are most nearly allied to the living plants of the eastern or Atlantic seaboard of the United States, and also by the occurrence of a rich Miocene flora in Greenland. As regards Greenland, Dr. Heer has determined that the Miocene plants indicate a temperate climate in that country, with a mean annual temperature at least 30° warmer than it is at present.

CHAPTER XXV.

PLIOCENE FORMATIONS.

THE Pliocene formations contain from 40 to 95 per cent. of existing species of *Mollusca*, the remainder belonging to extinct species. They are divided by Sir Charles Lyell into two divisions, the Older Pliocene and Newer Pliocene.

The Pliocene deposits of Britain occur in Suffolk, and are known by the name of "Crags," this being a local term used for certain shelly sands, which are employed in agriculture. Two of these Crags are referable to the Older Pliocene, viz., the White and Red Crags, and one belongs to the Newer Pliocene, viz., the Norwich Crag. The relative position of the older Crags to the subjacent Eocene rocks is shown by the annexed section (Fig. 190).

FIG. 190.—Section showing the position of the Coralline Crag, resting unconformably upon the London Clay.

The *White* or *Coralline Crag* of Suffolk is the oldest of the Pliocene deposits of Britain, and is an exceedingly local formation, occurring in but a single small area, and having a maximum thickness of not more than 50 feet. It consists of soft sands, with occasional intercalations of flaggy limestone. Though of small extent and thickness, the Coralline Crag is of importance from the number of fossils which it contains. The name "Coralline" is a misnomer; since there are few true Corals, and the so-called "Corals" of the formation are really *Mollusks*, related to the living Sea-mosses and Sea-mats, but often of very singular forms. The Shells of the Coralline Crag are mostly such as inhabit the seas of temperate regions;

but there occur some forms usually looked upon as indicating a warm climate, such as a Volute (Fig. 191) and a *Pyrula* (Fig. 192). With these occurs a Sea-urchin (*Temnechinus*, Fig. 193), the only living species of which is found in the In-

Fig. 191.—*Voluta Lamberti.* Young individual.

Fig. 192.—*Pyrula reticulata.*

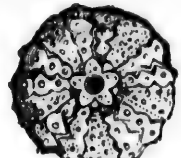


Fig. 193.—*Temnechinus excavatus.*

dian Ocean. Altogether the Coralline Crag contains more than 300 species of marine shells, of which 52 per cent. are living forms.

The *Upper* or *Red Crag* of Suffolk—like the Coralline Crag—has a limited geographical extent and a small thickness, rarely exceeding 40 feet. It consists of quartzose sands, usually deep red or brown in color, and charged with numerous fossils. Most of the organic remains of the Red Crag are *Mollusca*, among which are Spindle-shells (*Fusus*), Purples (*Purpura*), Dog-whelks (*Nassa*), Cowries (*Cyprœa*), etc. (*see* Figs. 194–197).

Fossils characteristic of the Red Crag.

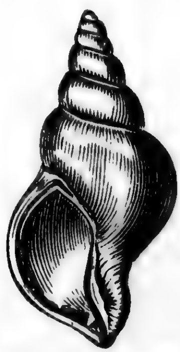


Fig. 194.—*Fusus contrarius.* (Reversed variety.)

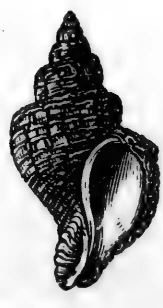


Fig. 195.—*Purpura tetragona.*

Fig. 196.—*Nassa granulata.*

Fig. 197.—*Cyprœa Europœa.*

Altogether more than 200 species of shells are known from the Red Crag, of which 60 per cent. are referable to existing species. The shells indicate upon the whole a temperate or even cold climate, decidedly less warm than that indicated by the organic remains of the Coralline Crag. It appears, therefore, that a gradual refrigeration was going on during the Pliocene period, commencing in the Coralline Crag, becoming intensified in the Red Crag, being still more severe in the Norwich Crag, and finally culminating in the Arctic cold of the Glacial period.

Besides the *Mollusca*, the Red Crag contains the ear-bones of Whales, the teeth of Sharks and Rays, and remains of the Mastodon, Rhinoceros, and Tapir.

The *Newer Pliocene* deposits are represented in Britain by the *Norwich Crag*, a local formation occurring near Norwich. It consists of incoherent sands, loams, and gravels, resting in detached patches, from two to 20 feet in thickness, upon an eroded surface of chalk. The Norwich Crag contains a mixture of marine, land, and fresh-water shells, with remains of fishes and bones of mammals; so that it must have been deposited as a local sea-deposit near the mouth of an ancient river. It contains altogether more than 100 marine shells, of which 89 per cent. belong to existing species. Of the Mammals, the two most important are an Elephant (*Elephas meridionalis*), and the characteristic Pliocene Mastodon (*M. Arvernensis*, Fig. 198), which is hitherto the only Mastodon found in Britain.

The following are the more important Pliocene deposits which have been hitherto recognized out of Britain:

FIG. 198.—*Mastodon Arvernensis.*—Third milk molar tooth, left side, upper jaw; grinding surface, natural size. Newer Pliocene.

1. In the neighborhood of Antwerp occur certain "crags," which are the equivalent of the White and Red Crag in part. The lowest of these contains less than 50 per cent. and the highest 60 per cent. of existing species of shells, the remainder being extinct.

2. Bordering the chain of the Apennines, in Italy, on both sides are a series of low hills made up of Tertiary strata, which are known as the Sub-Apennine beds. Part of these is of Miocene age, part is Older Pliocene, and a portion is Newer Pliocene. The Older Pliocene portion of the Sub-Apennines consists of blue or brown marls, which sometimes attain a thickness of 2,000 feet.

3. In the valley of the Arno, above Florence, are both Older and Newer Pliocene strata. The former consist of blue clays and lignites, with an abundance of plants. The latter consist of sands and conglomerates, with remains of large Carnivorous Mammals, Mastodon, Elephant, Rhinoceros, Hippopotamus, etc.

4. In Sicily, Newer Pliocene strata are probably more largely developed than anywhere else in the world, rising sometimes to a height of 3,000 feet above the sea. The series consists of clays, marls, sands, and conglomerates, capped by a compact limestone, which attains a thickness of from 700 to 800 feet. The fossils of these beds belong almost entirely to living species, one of the commonest being the Great Scallop of the Mediterranean (*Pecten Jacobœus*).

5. Occupying an extensive area round the Caspian, Aral, and Azof Seas are Pliocene deposits known as the "Aralo-Caspian" beds. The fossils in these beds are partly freshwater, partly marine, and partly intermediate in character, and they are in great part identical with species now inhabiting the Caspian. The entire formation appears to indicate the former existence of a great sheet of brackish water, forming an inland sea, like the Caspian, but as large as, or larger than, the Mediterranean.

6. In the United States, strata of Pliocene age are found in North and South Carolina. They consist of sands and clays, with numerous fossils, chiefly *Mollusks* and *Echinoderms*. From 40 to 60 per cent. of the fossils belong to existing species. On the Loup Fork of the river Platte in the Upper Missouri region are strata which are also believed to be referable to the Pliocene period, and probably to its upper division. They are from 300 to 400 feet thick, and contain land shells with the bones of numerous Mammals, such as Camels, Rhinoceroses, Mastodons, Elephants, the Horse, Stag, etc.

Life of the Pliocene Period.—As regards the life of the Pliocene period, it is sufficient to indicate two general considerations. In the first place, we have to notice that the introduction upon the globe of existing species of animals was carried on rapidly during this period. In the Older Pliocene deposits the number of shells of existing species is only from 40 to 60 per cent.; but in the Newer Pliocene the proportion of existing species rises to as much as 80 to 95 per cent. The Mammals still all belong to extinct species, but modern types gradually supersede the more antique forms of the Eocene and Miocene periods. In the second place, there is good evidence to show that the Pliocene period was one in which the climate of the northern hemisphere gradually became colder. In the Miocene period, as we have seen, Europe possessed a climate probably very similar to that now enjoyed by the Southern States of the Union, and certainly very much warmer than its present climate. In the Older Pliocene, northern forms, on the other hand, predominate among the shells, though some of the types of warmer regions still survive. In the Newer Pliocene, the *Mollusca* are almost exclusively such as inhabit the seas of temperate, or even cold regions. It might be thought that the occurrence of Mammals such as the Elephant, Rhinoceros, and Hippopotamus, would prove that the climate of Europe and the United States must have been a hot one during the later portion of the Pliocene period. We have, however, reason to believe that many of these extinct quadrupeds were more abundantly furnished with hair, and more adapted to withstand a cool temperature, than any of their living congeners.

POST-TERTIARY PERIOD.

CHAPTER XXVI.

POST-PLIOCENE DEPOSITS.

LATER than any of the Tertiary formations are a series of deposits which are spoken of as *Post-Tertiary* or *Quaternary*, and which are characterized by the fact that all the contained shells belong to existing species. The Post-Tertiary deposits are divided by Sir Charles Lyell into *Post-Pliocene*, in which the shells belong entirely to existing species, but *some of the Mammals are extinct*, and the *Recent*, in which the *shells and the Mammals alike belong to existing species.*

The most important of the Post-Pliocene deposits are the *Glacial* formations; but we have sometimes evidence of Post-Pliocene beds of *pre-glacial* age. Thus, in the cliffs of the Norfolk coast in Britain we find reposing upon the Newer Pliocene Norwich Crag an ancient land-surface which is known as the "Cromer Forest-bed." This consists of an ancient soil, having imbedded in it the stumps of many trees, still in an erect position, with remains of living plants, and the bones of recent and extinct quadrupeds. It is overlaid by fresh-water and marine beds, all the shells of which belong to existing species, and it is finally surmounted by true "glacial drift." While all the shells and plants of the Cromer Forest-bed and its associated strata belong to existing species, the Mammals are partly living, partly extinct. Thus, we find the existing Wolf, Bison, Reindeer, Beaver, Walrus, etc., side by side with three extinct Elephants, the Rhinoceros, and Hippopotamus, and a gigantic extinct Beaver. Among the Elephants are two Pliocene species, viz., *Elephas meridionalis* (Fig. 199), and *Elephas antiquus*. The third species is the Mam-

moth (*Elephas primigenius*), which has as yet only been found in Post-Pliocene deposits.

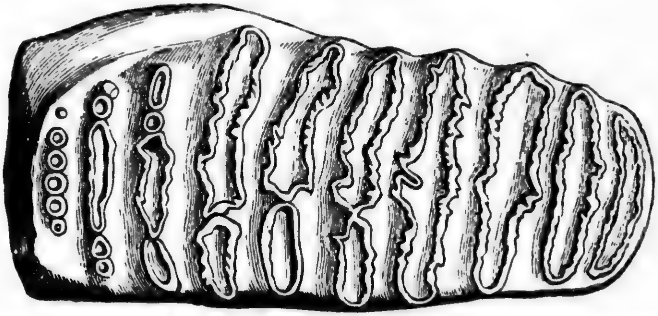


FIG. 199.—Molar tooth of *Elephas meridionalis*, ⅓ nat. size. Pliocene and Post-Pliocene.

GLACIAL DEPOSITS.

We come now to speak of a great series of beds which are widely spread over both Europe and America, and which were formed at a time when the climate of these countries was very much colder than it is at present, and approached more or less closely to what we see at the present day in the Arctic regions. These deposits are known by the general name of the *Glacial deposits*, or by the more specialized names of the Drift, the Northern Drift, the Bowlder Clay, the Till, etc.

These glacial deposits are found in Britain as far south as the Thames, over the whole of Northern Europe, in all the more elevated portions of Southern and Central Europe, and over the whole of North America, as far south as the 39th parallel. They generally occur as sands, clays, and gravels, spread in widely-extended sheets over all the geological formations alike, except the most recent, and are commonly spoken of under the general term of "Glacial drift." They vary much in their exact nature in different districts, but they universally consist of one, or all, of the following members:

1. *Unstratified* clays, or loams, containing numerous angular or sub-angular blocks of stone, which have often been transported for a greater or less distance from their parent rock, and which often exhibit polished, grooved, or striated surfaces. These beds are what is called *Bowlder-clay*, or *Till*.

2. Sands, gravels, and clays, often more or less regularly *stratified*, but containing erratic blocks, often of large size, and with their edges *unworn*, derived from considerable distances

from the place where they are now found. In these beds it is not at all uncommon to find fossil shells; and these, though of existing species, are mostly of an Arctic character, comprising a majority of forms which are now exclusively found in the icy waters of the Arctic seas. These beds are often spoken of as "Stratified Drift."

3. *Stratified* sands and gravels, in which the pebbles are *worn* and rounded, and which have been produced by a rearrangement of ordinary glacial beds by the sea. These beds are commonly known as "Drift-gravels," or "Regenerated Drift."

The glacial deposits exhibit many phenomena of interest which cannot be noticed here, and they have been produced by the action of glaciers, continental ice, coast-ice, and icebergs, after the manner described in the earlier portion of this work. The general sequence of the phenomena of the Glacial period, and the general nature of the resulting deposits, will be best brought out by examining a single district, and no better example can be found than Scotland.

In considering the glaciation of Scotland, we have evidence of three periods: 1. The period of the Lower Bowlder Clay; 2. The period of the Upper Bowlder Clay; and 3. The period of the recession and final disappearance of the glaciers, or the period of the Moraines.

1. The lowest glacial deposit of Scotland is what is known as the *Till*, or *Lower Bowlder Clay*, consisting of thoroughly unstratified, stiff clay, containing numerous angular blocks or "bowlders" of rock, which are generally more or less polished, grooved, and striated. The surface of rock beneath the Till is everywhere ice-worn, polished, smoothed, and furrowed, just like the rock beneath a glacier. The Lower Bowlder Clay gives evidence of a time at the commencement of the Glacial period, when Scotland was very much more elevated than it is at present, and when all its mountains were covered by a continuous ice-sheet, constantly moving seaward, as we now see in Greenland. By the abrasion of this ice-sheet upon the rocks beneath was produced the Lower Bowlder Clay. That this theory as to the origin of the Till is correct—namely, that it was produced by land-ice, and not by icebergs—is shown by the absence in it of marine shells, the generally not perfectly angular condition of the included blocks, the fact that the blocks are never far transported, and the universally striated, furrowed, and polished condition of the fundamental rocks on which it rests.

During the formation of the Lower Bowlder Clay, the land must have been slowly sinking beneath the sea, till ultimately the greater part of it must have been submerged, nothing remaining above water except the highest and most mountainous districts.

2. At the commencement, therefore, of the period of the Upper Bowlder Clay, Scotland must have been an archipelago, its highest mountains forming islands projecting above the waters of an icy ocean. Every peak which still remained above water would be the seat of glaciers, which would grind their way down to the sea, and would finally break off as huge icebergs, laden with sand, clay, and stones, derived from the moraines. Drifting before the wind, or hurried along by oceanic currents, the rock-laden bergs would ultimately melt and deposit their burden at the bottom of the sea, by the waves and currents of which it would be more or less sorted and stratified, and the shells of which it might come to contain as fossils.

In this way, then, was produced the *Upper Bowlder Clay*, a deposit of sands and clays, generally more or less distinctly stratified, including more or fewer erratic blocks, which have usually been transported to great distances from their parent rock, and often containing marine shells of Arctic species.

In this period, also, were formed masses of reassorted drift, or "Drift-gravels," by the action of the sea upon the older drift. These drift-gravels resemble stratified drift in most respects, but the blocks which they contain are more or less completely rounded and water-worn, and all their striæ and grooves are obliterated.

3. The land now commenced again to rise from beneath the sea, and it must have reached its present level, or one a little higher. The cold of the Glacial period still continuing, the higher regions were occupied by great glaciers, filling their valleys. These have left behind them, in many places, traces of their presence in the form of *terminal moraines.* These appear as transverse ridges, or rows of mounds crossing valleys from side to side. Sections of them show that they consist of *unstratified* materials, with many angular blocks, some of which are striated and polished. They mark the ancient limit of the glacier, and there may be several in the same valley, indicating pauses in the recession and ultimate disappearance of the glacier. In some cases, also, these ancient moraines have served to dam up the stream of the valley, and thus to give rise to a larger or smaller lake. Finally, under the in-

fluence of a gradually-increasing temperature, the glaciers disappeared altogether, and their place was taken by the present mountain-torrents.

As before remarked, the Bowlder Clay occasionally contains the remains of marine shells. The greatest height to which marine shells have been traced in the Drift of Britain is about 1,400 feet, indicating that the country was submerged to at least this amount below its present level beneath the waters of the glacial sea. All the glacial shells belong to living species, but they comprise many forms which belong exclusively to Arctic seas. During the Glacial period these Arctic shells were enabled to migrate southward, in consequence of the extension of the Arctic conditions necessary for their existence. When the Glacial period again finally ended, they were either destroyed by the uncongenial warmth, or gradually receded back again to the north. Some of the shells characteristic of the Scotch Drift are figured below.

SHELLS OF THE DRIFT OF SCOTLAND.

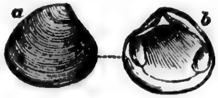


FIG. 200.—*Astarte borealis.*

FIG. 201.—*Leda oblonga.*

FIG. 202.—*Saxicava rugosa.*

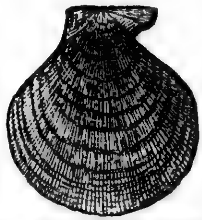


FIG. 203.—*Pecten islandicus.*

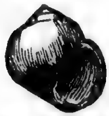


FIG. 204—*Natica clausa.*

FIG. 205—*Trophon clathratum.*

Similar evidence of a like sequence of phenomena can be detected in Wales and the north of England. That is to say, there was first an intensely cold period, in which the land was probably much more elevated than it is at present, and all the higher regions were covered with gigantic glaciers, or a continuous ice-sheet; secondly, a submergence took place to a depth of at least 1,400 feet below the present sea-level, all the higher mountains standing out in the icy sea as the sources of glaciers and icebergs; thirdly, the land was re-elevated, and there was a second period of glaciers, in which the cold was not so intense, and the glaciers consequently smaller than in the first period.

Evidence of an essentially similar state of affairs exists over the whole of Northern Europe, in the Alps, in the Himalayas, and elsewhere. In the United States, as far south as the 39th parallel, the surface of the fundamental rocks is striated, grooved, and polished. Unstratified sands and clays, with large erratic bowlders, cover a great portion of the country, and, whenever these deposits contain fossil shells, a considerable proportion are such as only exist at the present day in the Arctic seas. As in the case of Europe, a large portion of the North American drift has been produced by floating bergs, during a period of submergence, but glaciers and continental ice likewise existed over large areas. As in the case of Europe, also, the Post-Pliocene Mammals lived through the cold of the Glacial period, remains of some of the larger forms having been found in both pre-glacial and post-glacial deposits.

CHAPTER XXVII.

VALLEY-GRAVELS AND CAVE-DEPOSITS.

THE remaining Post-Pliocene deposits which require notice are valley-gravels and cave-deposits. In the first place, however, it may be as well to define a rather vague term, which is commonly used in connection with the Post-Tertiary deposits, namely, the term *alluvium*. Between the ordinary soil of every country and the subjacent fundamental rocks may be found, in places, intervening deposits of incoherent sands, gravels, or mud. All these deposits are loosely called by the general name of *alluvium* (Lat. *alluvio*, an inundation), because they resemble the kinds of deposits which are formed by the overflowing of rivers. Much of this so-called alluvium is now known to be really of glacial origin, and to belong to the Glacial period. There are, however, other alluvial deposits of Post-Tertiary age which really have been produced by rivers, and are known properly as *alluvium*.

Every river produces at the present day beds of fine mud and loam, and accumulations of gravel, which it deposits at various parts of its course; the gravel generally occupying the lowest position, and the finer sands and mud coming above. Numerous deposits of a similar nature are found in most countries in various localities, and at various heights above the present channels of our rivers. Many of these fluviatile (Lat. *fluvius*, a river) deposits consist of fine loam, worked for brick-making, and known as "Brick-earths;" and they have yielded the remains of numerous extinct Mammals, of which the Mammoth (*Elephas primigenius*) is the most abundant. In the valley of the Rhine these fluviatile loams (known as "Loess") attain a thickness of several hundred feet, and contain land and fresh-water shells of existing species. With these occur the remains of Mammals, such as the Mammoth

and Woolly Rhinoceros; and in one locality a human lower jaw has been disinterred from the same beds, the authenticity of which appears to be free from doubt. According to Sir Charles Lyell, these fluviatile loams in the Rhine Valley are the result of the impalpable mud and sand produced by the grinding action of the great Swiss glaciers, and then conveyed by the rivers to lower levels.

High-level and Low-level Valley Gravels.—It is very common to meet in the valley of any river with two or more sets of gravels and loams, formed by the river itself, but formed at times when the river ran at different levels. A reference to the accompanying diagram will explain the origin and nature of these deposits (Fig. 206). When a river first

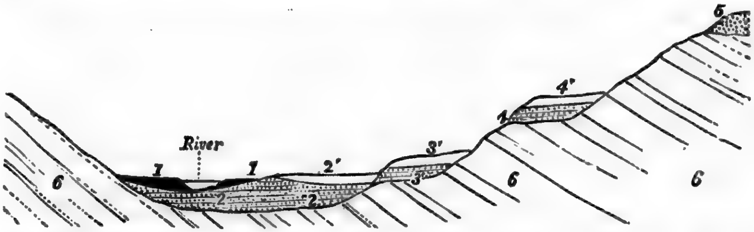


Fig. 206.—Recent and Post-Pliocene alluvial deposits.—1. Peat of the recent period; 2. Gravel of the modern river; 2'. Loam of the modern river; 3. Lower-level valley-gravel with bones of extinct Mammals (Post-Pliocene); 3'. Loam of the same age as 3; 4. Higher-level valley-gravel (Post-Pliocene); 4'. Loam of the same age as 4; 5. Upland gravels of various kinds (often glacial drift); 6. Older rocks. (After Sir Charles Lyell.)

begins to occupy a particular line of drainage, and to form its own channel, it will deposit fluviatile sands and gravels along its sides. As it goes on deepening the bed or valley through which it flows, it will deposit other fluviatile strata at a lower level beside its new bed. In this way have arisen the terms "high-level" and "low-level gravels." We find, for instance, a modern river flowing through a valley which it has to a great extent or entirely formed itself; by the side of its immediate channel we may find gravels, sand, and loam (Fig. 206, 2, 2') deposited by the river flowing in its present bed. These are *recent* fluviatile or alluvial deposits. At some distance from the present bed of the river, and at a higher level, we may find other sands and gravels, quite like the recent ones in character and origin, but formed at a time when the stream flowed at a higher level, and before it had excavated its valley to its present depth. These (Fig. 206, 3, 3') are the so-called "*low-level* gravels" of a river. At a still higher level, and

still farther removed from the present bed of the river, we may find another terrace, composed of just the same materials as the lower one, but formed at a still earlier period, when the excavation of the valley had proceeded to a much less extent. These (Fig. 206, 4, 4′) are the so-called "*high-level* gravels" of a river, and there may be one or more terraces of these.

The important fact to remember about these fluviatile deposits is this: that here the ordinary geological rule is reversed. The high-level gravels are, of course, the highest, so far as their actual elevation above the sea is concerned, but geologically the lowest, since they are obviously much older than the low-level gravels, as these are than the recent gravels. How much older the high-level gravels may be than the low-level ones, it is impossible to say. They occur at heights varying from 10 to 100 feet above the present river-channels, and they are, therefore, older than the recent gravels by the time required by the river to dig out its own bed to this depth. How long this period may be our data do not enable us to determine accurately, but, if we are to calculate from the observed rate of erosion of the actually existing rivers, the period between the different valley-gravels must be a very long one.

The lowest or recent fluviatile deposits (Fig. 206, 2, 2′) which occur beside the bed of the present river are referable to the Recent period, as they contain the remains of none but living Mammals. The two other sets of gravels are Post-Pliocene, as they contain the bones of extinct Mammals, mixed with land and fresh-water shells of existing species. Among the more important extinct Mammals of the low-level and high-level valley-gravels may be mentioned the *Elephas antiquus* (Fig. 207), the Mammoth (*Elephas primigenius*), the Woolly Rhinoceros (*R. tichorhinus*), the Hippopotamus, the Cave-lion, and the Cave-bear.

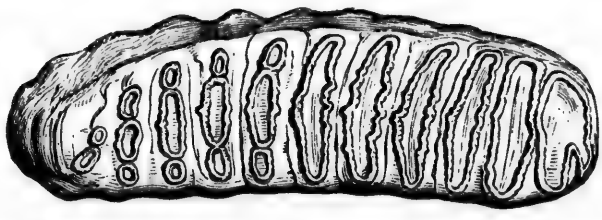


FIG. 207.—Molar of *Elephas antiquus*, ⅙ natural size. Pliocene and Post-Pliocene.

Mixed in these Post-Pliocene gravels with the bones of extinct Mammals occur unquestionable remains of man, in the

form of worked flints or flint implements. These, though very roughly executed, are of such a nature as to leave no doubt, on the mind of any who have examined them, as to their being truly of human workmanship. They differ much in shape, being commonly like a cat's tongue, or like the head of a spear; and they have been laboriously chipped with a stone to their present shape.

As regards the antiquity of these flint implements and of the races of men who employed them, it will be sufficient to indicate the following general considerations:

1. Man must have coexisted in Western Europe with a number of large Mammals which are now wholly extinct. We do not know either the causes of such extinction, or how long a period is required to consummate the destruction of a group of species; but we know of no mammalian species that has become extinct during the historical period.

2. The extinct Mammals with which man coexisted are referable to species which require a very different climate to that now prevailing in Western Europe. Most of them, in fact, are referable to genera, the living representatives of which are exclusively found in tropical or sub-tropical regions. How long a period, however, has been consumed in the bringing about the climatic changes thus indicated, we have no means of calculating accurately.

3. The position of some of the gravels with flint implements is many feet (in one instance 100 feet) above the present river-bed. As before remarked, however, we cannot accurately judge of the period required for the river to cut its channel to its present depth, at any rate until we are certain that the river in past time has not exceeded its present velocity and volume of water.

4. The implements themselves bear evidence of an exceedingly barbarous condition of human life. The makers of the flint implements were clearly without any knowledge of the metals. Not only so, but their workmanship is extraordinarily inferior to that of the later tribes who were likewise unacquainted with metals and who also used nothing but tools of stone. For this reason the period of the makers of the flint implements has been called the *Palæolithic* age (Gr. *palaios*, ancient; *lithos*, stone); while the later and more advanced age of stone has been termed the *Neolithic* period (Gr. *neos*, new; *lithos*, stone).

Cavern-deposits.—We come now to consider a class of deposits essentially similar to the older valley-gravels, but

occurring in caves. Caves, in the great majority of instances, occur in limestone. When this is not the case, it will generally be found that they occur along lines of sea-coast, or along lines which can be shown to have anciently formed the coast-line. There are many caves, however, in the making of which it can be shown that the sea has had no hand, and these are most of the caves of limestone districts. These owe their origin to the solvent action upon lime of water holding carbonic acid in solution. The rain which falls upon a limestone district absorbs a certain amount of carbonic acid from the air, or from the soil. It then percolates through the rock, generally along the lines of jointing so characteristic of limestones, and in its progress it dissolves and carries off a certain quantity of carbonate of lime. In this way, the natural joints and fissures in the rock are widened, as can be seen at the present day in any or all limestone districts. By a continuance of this action for a sufficient length of time, caves may ultimately be produced. Nothing, also, is commoner in a limestone district than for the natural drainage to take the line of some fissure, dissolving the rock in its course. In this way we constantly meet in limestone districts with springs issuing from the limestone rock—sometimes as large rivers, the waters of which are charged with carbonate of lime, obtained by the solution of the sides of the fissure through which the waters have flowed. By these and similar actions, every district in which limestones are extensively developed will be found to exhibit a number of natural caves, rents, or fissures. The first element, therefore, in the production of cave-deposits is the existence of a period in which limestone rocks were largely dissolved, and caves were formed in consequence of the then existing drainage taking the line of some fissure.

Secondly, there must have been a period in which various deposits were accumulated in the caves thus formed. These cavern-deposits are of very various nature, consisting of mud, loam, gravel, or breccias of different kinds. In all cases, these materials have been introduced into the cave at some period subsequent to, or contemporaneous with, the formation of the cave. Sometimes the cave communicates with the surface by a fissure through which sand, gravel, etc., may be washed by rains or by floods from some neighboring river. Sometimes the cave has been the bed of an ancient stream, and the deposits have been formed as are fluviatile deposits at the surface. Or, again, the river has formerly flowed at a greater elevation than it does at present, and the cave has been filled with

fluviatile deposits by the river at a time prior to the excavation of its bed to the present depth (Fig. 208). In this last case, the cave-deposits obviously bear exactly the same relation in point of antiquity to recent deposits, as do the low-level and high-level valley-gravels to recent river-gravels. In

FIG. 208.—Section of limestone valley and cave.—*a*, Cavern, partly filled with cave-earth; *b*, High-level gravels; *c*, Recent gravels of present river (*e*); *d*, Fissure filled with high-level gravel; *e*, Bed of present river.

any case, it is necessary for the physical geography of the district to change to some extent, in order that the cave-deposits should be preserved. If the materials have been introduced by a fissure, the cave will probably become ultimately filled to the roof, and the aperture of admission thus blocked up. If a river has flowed through the cave, the surface configuration of the district must be altered so far as to divert the river into a new channel. And, if the cave is placed in the side of a river-valley, as in Fig. 208, the river must have excavated its channel to such a depth that it can no longer wash out the contents of the cave even in high floods.

If the cave be entirely filled, the included deposits generally get more or less completely cemented together by the percolation through them of water holding carbonate of lime in solution. If the cave is only partially filled, the dropping of water from the roof holding lime in solution, and its subsequent evaporation, would lead to the formation over the deposits below of a layer of stalagmite, perhaps several inches, or even feet, in thickness. In this way cave-deposits, with their contained remains, may be hermetically sealed up and preserved without injury, for an altogether indefinite period of time.

The great interest of cavern-deposits is to be found in the fact that they in very many cases contain the bones of extinct as well as living Mammals, associated with the implements, and in some cases even the bones, of man. The number of instances in which this association of the works or bones of man with remains of extinct Mammals in cave-deposits is

known to occur, is now so great that it is unnecessary to dwell upon any particular case, and it will be sufficient shortly to summarize the more important facts under this head.

The human implements which have been found in cave-deposits are in the great majority of instances referable to the age of stone; and, when associated with extinct Mammals, they are not only always of stone, but are referable to the Palæolithic period. They consist chiefly of stone hatchets or other tools, with occasional implements worked out of bone. In some of the caves, however, the stone implements, though of a very rude construction, nevertheless show a decided advance on the flint tools of the older valley-gravels.

In some cases, with implements of human workmanship have been found the bones of man, associated with the bones of extinct Mammals.

The human implements are so mixed with the bones of extinct quadrupeds as to render it unquestionable that man existed contemporaneously with these extinct animals.

The more important extinct Mammals which have been found in cave-deposits in Europe, along with the remains of man, are the Mammoth (*Elephas primigenius*, Fig. 209), the

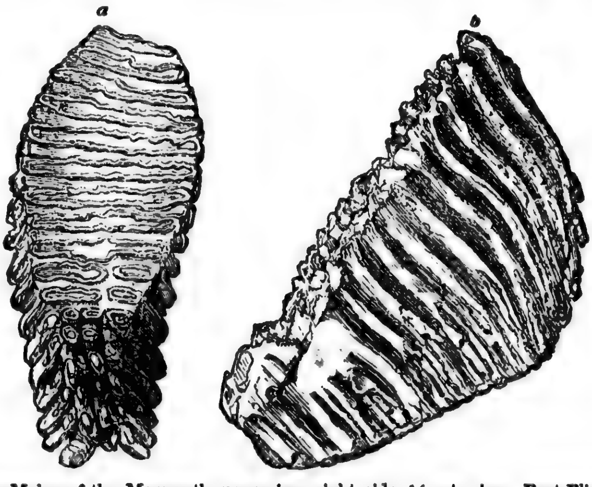


Fig. 209.—Molar of the Mammoth, upper jaw, right side, ¼ nat. size. Post-Pliocene.—*a*, Grinding surface; *b*, Side view.

Woolly Rhinoceros (*R. tichorhinus*), other species of Elephant and Rhinoceros, the Cave-lion (*Felis spelæa*), the Cave-bear (*Ursus spelæus*), and the Cave-hyæna (*Hyæna spelæa*, Fig.

210). Many more might be added to these, but the above are sufficient to show that the Mammals of the caves are

FIG. 210.—Lower jaw of the Cave-hyæna, ½ nat. size. Post-Pliocene.

the same as those which occur in the ancient valley-gravels along with the implements of man.

In certain of the caves of the south of France the remains indicate a transition between the Palæolithic and Neolithic periods. The implements are somewhat improved in workmanship, and some of the bones are artistically carved so as to represent animals, a recognizable portrait of the *Mammoth* in its living condition having been in one instance discovered. The Mammals of these caves, with one or two doubtful exceptions, are of living species, but they are mostly such as require a colder climate than the south of France, and are only found at the present day in much more northern latitudes. Of these the most abundant is the Reindeer, and this would imply that man coexisted with these animals at a time when the climate of the south of France approximated more or less closely to what we see at the present day in Lapland.

In Australia, cave-deposits have been found which have yielded the bones of numerous extinct Mammals, more or less closely allied to the living quadrupeds of that region, but of gigantic size, comparatively speaking. Thus we find gigantic Kangaroos, Wombats, and Carnivorous Marsupials, and others also Marsupial, but not represented at the present day.

In like manner the cave-deposits and other Post-Pliocene formations of South America have yielded the remains of numerous Mammals, mostly allied to the living quadrupeds of that continent, but generally of much greater size. Thus, we have gigantic Sloths and huge Armadillos, together with animals allied to the living Llamas, and Monkeys belonging to the same group of the *Quadrumana* as is now characteristic of South America.

CHAPTER XXVIII.

RECENT PERIOD.

The last geological period is the Recent period, characterized by the fact that all the Mammals, as well as all the Mollusks, are referable to existing species. This being the case, we have chiefly to deal with the Recent period in connection with the remains of man. So far as man is concerned, the Recent period admits of subdivision into three ages—the Age of Stone, or Neolithic period, the Age of Bronze, and the Age of Iron.

I. In the *Age of Stone* the implements which are found are always of stone, bone, or wood, showing that the metals must have been unknown. The bones of Mammals accompanying the implements are all of living species, and this distinguishes this, the *Neolithic* period, from the older *Palæolithic* period in which some of the Mammals were extinct. The implements, also, of this period are more artistically fashioned than those of the earlier period. Another fact to be remembered is, that the bones of animals which occur associated with the human remains of the later Stone Age are those of *wild* animals, showing that the men of this period were hunters and not agriculturists. Thus we have numerous remains of the Deer, Wild-boar, and Wild-ox, but none of any domestic animal, such as the Pig, Goat, or Sheep.

II. In the *Age of Bronze* metals had been discovered, and the use of stone in making implements was gradually discarded. Stone, however, must have been only very slowly given up, for *some* of the implements of this age are generally of stone, though these are certainly more artistically worked than those of the Neolithic period. The curious thing, however, about the discovery of metals is, that *bronze* should have been found out at such an early stage, seeing that it is an

alloy of the two metals copper and tin. Copper is a moderately abundant metal, and its discovery might have been looked for; but tin is not only difficult to recognize in its ores, but is very limited in its occurrence. In fact, we do not know of any locality from which tin could at that period have been obtained in Europe except Cornwall; so that the Age of Bronze must have been one in which commerce had developed itself to a considerable extent. It is to be remembered, however, that in some places, as in Hungary and Transylvania, there appears to have been an intermediate age—the Age of Copper—in which copper alone was in use. The civilization of the Age of Bronze was also much further advanced than that of the Neolithic period. The implements are often very beautifully made and are of various shapes. Agriculture had begun to be practised, as shown by the occurrence of sickles, with carbonized grains of wheat and barley, and even pieces of bread. And, the bones of animals associated with the implements are those of domesticated varieties, such as the domestic Ox, the Pig, and the Goat.

III. Lastly, we have the *Age of Iron*, in which iron was discovered and gradually supplanted bronze in the manufacture of all instruments requiring a cutting edge. All other articles continued to be made of bronze up to a late period, in fact, until the discovery of steel; for even the Greeks and the Romans used bronze largely for all ordinary purposes.

As regards the localities in which the records of these three periods of human civilization are found, the following more celebrated ones may just be mentioned:

1. *Kitchen-Middens* of Denmark. These are refuse-heaps found on the coast of the Danish islands of the Baltic, and consisting of the accumulated leavings of the meals of an aboriginal race during a long period. They are composed almost entirely of the castaway shells of the Oyster, Mussel, Cockle, and other eatable shell-fish, with the bones of animals, all wild except the Dog. They contain implements of stone, bone, or wood only, and are, therefore, referable to the Age of Stone.

2. The *Danish Peat-mosses*. The lower portions of the peat-mosses of Denmark contain stone implements, with trunks of the Scotch fir, a tree which has not existed in Denmark within the historical period. Higher portions of the Danish peat contain implements of bronze mixed with those of stone, and associated with the oak, a tree now very scarce in Denmark, and almost supplanted by the beech.

3. The *Lake-dwellings of Switzerland.* The Swiss lakes have been found in many cases to contain the remains of ancient habitations, which are called Lake-dwellings, because they consisted of villages built upon platforms supported upon piles driven into the bottom of the lake. Some of the lake-dwellings are much older than the others, and are referable to the Neolithic period, as they yield nothing but implements of stone. Some, however, are referable to the Age of Bronze, having yielded numerous bronze implements (axes, lances, bracelets, fish-hooks, sickles, etc.), with tolerably artistic pottery. Lastly, some few of the lake-dwellings have yielded tools of iron, and must, therefore, be referred to the Age of Iron.

SCARCITY OF HUMAN BONES.—As regards the scarcity of human bones in all these recent deposits, it is difficult to give a universal or adequate explanation. In the Danish peat and Swiss lake-dwellings exceedingly few bones of man have been detected, and this has been ascribed, probably with truth, to the fact that these early races of man must have been in the habit of burning their dead.

In the Neolithic period the custom seems to have prevailed, in some places at any rate, of burying the dead in vaults constructed of large undressed blocks of stone. Many skulls, therefore, have been obtained from these, and they show that the men of the Neolithic period had what is called

FIG. 211.—Short-headed skull of the Age of Stone.

FIG. 212.—Long-headed skull of the Age of Iron.

the "short-headed" type of skull. That is to say, the skull (Fig. 211) was more or less approximately spherical, rounded in every direction, like the skull of the modern Laplander.

The skulls of the Bronze Age are not known in sufficient numbers for us to be able to determine their general type. The skulls, however, of the Age of Iron are well known, and these belong to the so-called "long-headed" type (Fig. 212), which prevails at the present day in Europe. In this type the greatest diameter of the skull is from before backward, and its shortest diameter is from side to side. The skull, therefore, when viewed from above is decidedly oval, and the forehead retreats more than in the short-headed type.

CHAPTER XXIX.

VOLCANIC AND TRAPPEAN ROCKS.

THE volcanic and trappean rocks are found—as might be expected from their having been originally fluid—in very different forms:

1. They occur as *overlying* masses (Fig. 213); that is to say, they are found as masses which have been poured forth in

FIG. 213.—Trap dividing and covering sandstone in the Isle of Skye. (MacCulloch.)

a molten state from some volcanic focus, and now rest upon or overlie other rocks. It is obvious, however, that every such overlying mass (as *c c*, in Fig. 214) must originally have communicated with the interior of the earth, whence its materials were in the first place derived. Hence to each overlying mass of lava or trap there must be a pipe or vein of igneous matter communicating with another underlying mass, and cutting through the rocks between. In many cases it is now impos-

FIG. 214.—Diagram representing the relations of the granitic, stratified, and trappean formations to one another.—*a*, Granitic and Metamorphic rocks; *b*, Stratified rocks; *c*, Volcanic or Trappean rocks.

sible to demonstrate the existence of such a communication, though there can be no question as to its necessarily being

present. In other cases, again, the whole overlying mass has been removed by denudation, and little or nothing has been left except the original pipe by which the melted matter reached the surface.

2. The Volcanic and Trappean rocks occur as masses or tabular sheets intercalated among other rocks (Fig. 215).

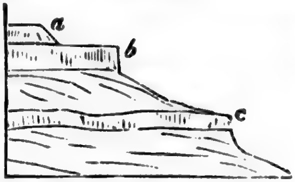


FIG. 215.—Step-like appearance of horizontal masses of trap.

As we shall see immediately, such masses may either conform to the stratification of the rocks above and below, or may cut across these at any angle. In any case, the presence of such horizontal or nearly horizontal masses generally leads to a peculiar step-like or terraced appearance, owing to the greater hardness of traps, and their superior power of resisting denudation. Hence the name "trap," from the Swedish *trappa*, a flight of steps (Fig. 215).

3. The volcanic and trappean rocks have been injected while in a fluid state into fissures, and now constitute more or less nearly vertical, wall-like masses, which cut through the other rocks, and are known as *dikes* or *veins* (Fig. 216).

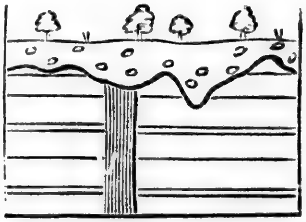


FIG. 216.—Strata intercepted by a trap-dike, and covered with alluvium.

AGE OF THE VOLCANIC AND TRAPPEAN ROCKS.—As regards the relative and absolute ages of the volcanic and trappean rocks, there are four principal tests: 1. Superposition; 2. Organic remains; 3. Mineral composition; 4. Included fragments.

Firstly, as to superposition, the following rules may be laid down:

If a volcanic or trappean rock rest upon a stratified rock,

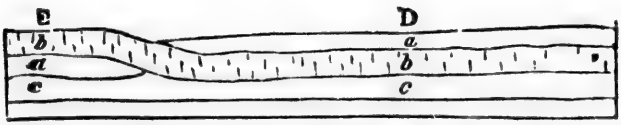


FIG. 217.—Section showing an intrusive sheet of trap (*b*), at first simply included between two fossiliferous beds (*a* and *c*), but ultimately cutting through *a*, and coming to overlie it.

the igneous mass must be the newest, and the stratified rock the oldest. Thus, in Fig. 217, the igneous sheet *b* reposes upon a fossiliferous bed *c* at D, and we may be quite certain that *c* was formed at the time when *b* was poured forth, and that it is, therefore, the oldest. The reverse of this, however, by no means holds good. When a stratified rock rests upon an igneous rock, as *a* upon *b*, in Fig. 217, it may perhaps be that the stratified rock is the youngest, but it by no means necessarily is so. If the igneous rock has been originally forced or injected between two sets of beds (as is actually the case with *b*, for it is seen to cut across *a* at the point E), then the igneous rock is younger than the beds between which it lies; the beds which rest upon it are older in spite of their being the highest. The test of age, therefore, by mere superposition, is not a certain one as applied to lavas and traps, but it applies with certainty to all *stratified* volcanic and trappean deposits, such as ashes, tuffs, and breccias. As we shall see, however, in explaining the distinction between "contemporaneous" and "intrusive" lavas and traps, the test of age by superposition becomes a very reliable one, even in the case of these, when combined with the metamorphism or alteration of the rocks above and below.

Secondly, the test of age by organic remains is in the nature of the case only very rarely applicable. It is only applicable in the case of ash-beds which have been produced by a sub-aërial volcano, and which have fallen on land; or in the case of ashes or tuffs which have been sorted by water, and which may contain marine or fresh-water fossils—as the former may include the remains of terrestrial animals. The laws here are exactly the same as in the case of ordinary sedimentary deposits, and need no further notice.

Thirdly, the test of age by mineral characters is even more uncertain in the case of volcanic rocks than in that of the aqueous formations. In some cases, no doubt, the mineral characters of a particular bed of trap or lava are sufficiently well marked and constant to allow of its being identified at distant points; but this is not very common, and of itself gives no clew as to the age of the rock.

Fourthly, the test of age by included fragments, when available, is a very certain one. If an aqueous rock be found to contain pebbles of a given igneous rock, then obviously the former is the youngest. Again, if an igneous rock contain determinable fragments of some aqueous rock, as sometimes occurs, then the igneous rock has been the last formed of the two.

Contemporaneous and Intrusive Traps.—There are two terms constantly employed in speaking of the volcanic and trappean rocks, which it is absolutely necessary to understand, viz.: the terms "contemporaneous" and "intrusive."

When a bed of lava or trap has been deposited as part of a stratified series—that is to say, when the lava or trap has been poured out so as to rest upon one set of beds, and then a second set of beds has been formed upon its cooled surface, so that the whole forms one continuous series—then the igneous rock is said to be *contemporaneous* or *interbedded.*

When, on the other hand, the igneous rock has been forced violently among the other rocks at some time subsequent to the formation and deposition of the latter, then the igneous rock is said to be *intrusive* (Fig. 218).

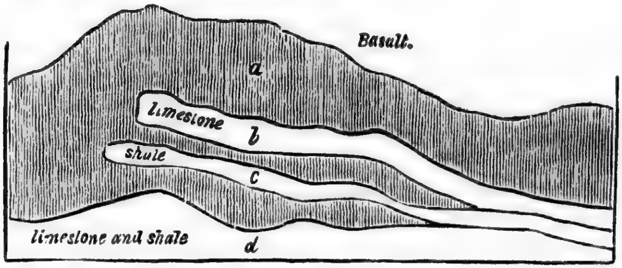


Fig. 218.—Trap intruded between displaced beds of limestone and shale, High Teesdale, Durham. (Sedgwick.)

A contemporaneous or interbedded trap belongs to the same geological period as the rocks among which it is situated. Thus, a Carboniferous trap, if interbedded, has been formed by a Carboniferous volcano, and belongs to the Carboniferous period.

An intrusive trap always belongs to a later period than the rocks through which it breaks. Thus, a Carboniferous trap, if intrusive, does not belong to the Carboniferous period, but to some later epoch—possibly to some very greatly later date. An intrusive trap in Carboniferous strata might, for instance, have been formed by a Tertiary volcano, and thus belong to the Tertiary period.

It is to be remembered, also, that as every trap or lava, even if contemporaneous, has come up through the crust of the earth through some conduit or fissure, so it must be intrusive as regards the rocks upon which it rests, not everywhere, but at some particular point or other.

As regards the distinction in practice between those lavas and traps which are contemporaneous or interbedded, and those which are intrusive, the following rules may be laid down:

a. If the igneous rock can be shown to cut across the stratified rocks at any point, so as to come into relation at different times with different beds, then it is almost certainly intrusive. Thus, the bed of trap *b*, in Fig. 217, would seem to be contemporaneous if only examined at the point D; but, when examined at E, it is seen to cut across the bed *a*, so that it is shown to be really intrusive.

b. If the igneous rock keep invariably at the same horizon, coming always into relation with the same beds both above and below, then it is interbedded.

c. If the beds which *rest upon the igneous rock* are in any way metamorphosed or altered by the heat of the originally melted mass, then the igneous rock is intrusive.

d. If only the beds *below* the igneous rock are metamorphosed or burnt, and those above it are unaffected, then the igneous mass is contemporaneous, since this shows that its upper surface had cooled before the higher beds were deposited upon it.

e. If the beds above the igneous rock contain fragments clearly derived from that rock, then we are dealing with a contemporaneous trap.

f. Lastly, if beds of trap or lava are clearly interstratified with beds of ash or tuff, then the igneous rock is in all probability contemporaneous.

TRAP-DIKES.—Little need be said here as to Trap-dikes. As has been already explained, they are vertical or nearly vertical wall-like masses of originally melted rock, forced during a paroxysm of volcanic activity into fissures in the crust of the earth. This being their mode of formation, they generally run tolerably straight—often for many miles—cutting across all the rocks in their course, whether these be aqueous or igneous. Hence, it is not at all uncommon to find dikes of trap traversing other trap-rocks, whether these be contemporaneous or intrusive.

It is hardly necessary to remark that every trap-dike is of necessity younger than all the rocks through which it cuts. This is obviously the case, though we may not be able in any given case to decide how much younger the dike may be than the walls of rock on either side.

As regards the metamorphism produced by traps, and especially by trap-dikes, it is easy to understand what occurs.

As the entire mass of the dike was originally fluid with heat, it would, of course, part most readily and rapidly with its heat at its sides, where the melted rock came into contact with the cold walls of the fissure. This produces a twofold effect—partly upon the dike itself, and partly upon the rocks forming the sides of the fissure. As regards the dike itself, as the process of cooling has gone on most slowly in the centre, it is here that the rock is most coarsely crystalline, and it becomes gradually more and more fine-grained as we approach the sides, where the cooling was most rapid. If the dike is porphyritic, containing distinct crystals—these will be found to become gradually smaller, and ultimately to disappear altogether toward the sides of the dike. As to the effect produced upon the rocks through which the dike cuts, these are always burnt and metamorphosed on both sides for a greater or less distance, the amount of metamorphism depending partly on the nature of the rock itself, and partly upon the size of the dike. The metamorphism presents nothing very special. The rocks are all indurated, their fossils are partly or wholly obliterated, their bedding is often destroyed, and frequently they have a reddened or burnt appearance. Their mineral characters, too, are changed; sandstones becoming quartzites, shales being converted into hornstone, limestones and chalk becoming saccharoid marbles, and so on.

With respect to the different ages of the different volcanic and trappean rocks, it would lead us too far to enter into any consideration of the characters of the igneous rocks of the great geological periods, and of the areas in which these are found. It is sufficient to say that the stratified rocks of every period are accompanied by contemporaneous igneous rocks, not in every country, but somewhere or other. Thus we have Palæozoic, Mesozoic, and Kainozoic traps; Silurian, Devonian, and Carboniferous traps, and so on.

CHAPTER XXX.

GRANITIC AND METAMORPHIC ROCKS.

GRANITIC ROCKS.—Granites, and the granitic rocks generally, make their appearance at the surface in large masses, which usually occupy considerable areas, and which send veins into the rocks with which they come in contact. With one or two exceptions, however, and these on a small scale, no granitic rock has been shown to rest upon any stratified rock; so that granite is said to be an "underlying" rock, and thus differs wholly from the overlying trappean rocks, which commonly repose upon stratified rocks (*see* Fig. 214, *a*).

Though granite never rests upon any other rock, it may and does break through the other rocks, altering those with which it comes in contact. Granite, therefore, would appear to be commonly an *intrusive* rock; and as such it is, of course, of later age than all the rocks through which it breaks. This would hold good, even if we suppose granite to have a purely metamorphic origin.

This fact has led to the very important generalization that *granites are of all ages.* When, for instance, we find a granite intruded among Tertiary strata, and altering them on its way to the surface, we know that it is of later age than the Tertiary rocks through which it breaks. The older geologists believed that the first rock which was formed was granite, and that the first step in the production of the crust of the earth was the formation of a continuous envelope of granite. Upon this coat of so-called "primeval" or "fundamental" granite they believed all the stratified formations to have been subsequently deposited. This may be so, but we are unable to point with certainty to any of this primeval granite. All we know is the undoubted fact that the aqueous rocks are always seen to rest upon granite. That is to say, if in any

particular region, or country, you can find out which was the oldest stratified rock ever deposited in that area, and if you can see what that rests upon, you will find it to repose upon granite. This is a very different thing, however, to the belief that all the granites which we see at the present day, at the surface of the earth, belong to a primeval crust of granite, and are, therefore, older than all the stratified rocks. In all probability *none* of the granites which we see at the present day belong to any such primeval crust; and we now know for certain that granitic formations have been produced during every great geological period, and are probably being formed at the present moment at great depths below the surface.

The chief tests by which the *age* of any given mass of granite may be determined are these:

1. Whenever sedimentary rocks are found reposing upon a mass of granitic rock, without showing any alteration near the line of junction, then the granite is the older of the two.

2. When, on the other hand, sedimentary rocks come into contact with granitic rocks, and are found to be metamorphosed near the line of contact, then it is clear that the granite, if not intrusive, is, at any rate, newer than the strata which it alters.

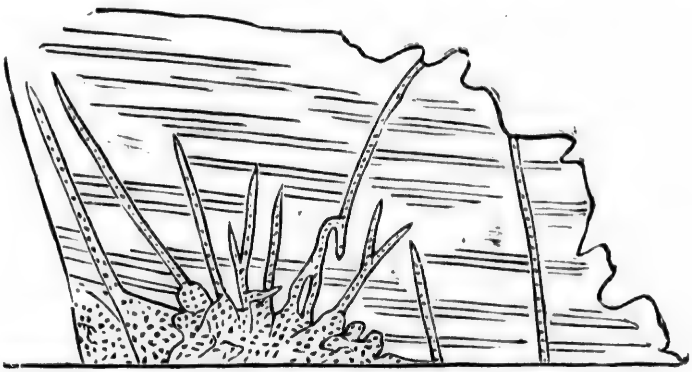


FIG. 219.—Granitic veins in hornblende slate. Cornwall.

Exactly the same thing is proved in a still more striking manner by the phenomena of granitic veins. Many granites, namely, agree with the intrusive trap-rocks, not only in altering the strata with which they come in contact, but also in sending veins into them (Fig. 219). And, these veins metamorphose all the rocks in their immediate vicinity, just as

trap-veins do; thus affording convincing proof that the granite is younger than the rock thus penetrated.

As regards the metamorphism produced by granitic veins, exactly the same phenomena are observable as in trap-veins, but generally upon a smaller scale, as the granite-veins are mostly smaller. Thus, the granite of the vein itself is more fine grained and less coarsely crystalline than that of the main mass, being, in fact, sometimes hardly distinguishable from trap; while the rocks in contact with the vein are baked, indurated, and altered in various ways. The metamorphism produced by granitic masses, also, does not differ in kind from that produced by traps, but it is usually much more extensive. Thus, the metamorphism produced by a mass of trap rarely extends more than a few feet or yards from the igneous rock itself. In the case of large masses of granite, however, the metamorphism may be traced for half a mile to a mile, or more, from the granitic mass. The metamorphism is also usually more intense than in the case of trap, the strata being converted for a great distance into such genuine metamorphic rocks as gneiss, mica-schist, or hornblende-schist.

With respect to the different ages of the granitic rocks, it is sufficient to say that there are Palæozoic, Mesozoic, and even Kainozoic granites; in fact, that there are granites belonging to most of the great geological periods except the latest. And, even in the case of these, there are doubtless contemporaneous granites also, but we do not see them, because granite is a rock formed at a great depth beneath the surface of the earth, and denudation has not yet been at work for a period of time sufficient to expose to our view the granites of the later Tertiary and Post-Tertiary epochs.

Metamorphic Rocks.—The chief regions in which Metamorphic rocks are developed over large areas, are North America, South America, the Alps, Norway and Sweden, the Highlands of Scotland and Wales; and in all these districts they are associated with lofty mountain-chains, and exhibit their most typical characters.

As to the *age* of the Metamorphic rocks, it is clear that they may be regarded as having a twofold age. In the first place, they must obviously belong to the geological period in which they were first deposited as unaltered sediments; and this, whether we can determine the date of this period or not. In the second place, every Metamorphic rock is secondarily referable to the period in which it was metamorphosed. The two periods in no way coincide with one another, the period

of metamorphism being always later—sometimes enormously so—than the period of original deposition. If, for example, we met with a group of Metamorphic rocks which we could prove to have been originally Liassic, and to have been metamorphosed in the Eocene period, then we should have to regard them as Liassic, looking to the time of their deposition, but as Eocene, if we regard them merely as Metamorphic rocks.

In determining the age of any given series of Metamorphic rocks, great difficulties are met with. The ordinary test of superposition, when available at all, only gives us the original age of the deposit, but gives no clew as to when the metamorphism took place. Mineral characters are altogether useless in determining the age of Metamorphic rocks, except as regards particular districts, and even then upon only a very limited scale. Fossils, as a matter of course, very rarely occur in the metamorphic rocks; and when they do, they can only tell us the original age of the deposit. Thus, it is now known that the Metamorphic rocks of the Highlands of Scotland are really of Lower Silurian age, as they have been shown to contain in some places fossils characteristic of this period.

As regards the actual ages of the different Metamorphic rocks, it is sufficient to say of them, as of the Granitic rocks, that they are of all ages. They commence in the Laurentian period, they are found in all the great geological periods which follow, and they are doubtless in process of formation at the present day. It is not meant by this, that we can point to the Metamorphic rocks of each formation; but no doubt there *are* such, and in many instances we can satisfactorily prove this.

CHAPTER XXXI.

MINERAL VEINS.

Deposits of minerals of different kinds are found in rocks of all ages, and principally in three different ways: 1. In beds; 2. In superficial *detritus;* 3. In veins.

1. Metallic ores not uncommonly occur in beds in other stratified deposits. This is the case, for instance, with the beds of clay-ironstone which occur in the Coal-measures. These deposits, however, differ in no way from the ordinary stratified or sedimentary formations, the ore having been deposited in the same way as the other materials in the bed or beds in which it is now found.

2. Metallic ores often occur in superficial *detritus* or *alluvium.* This is the case with the platinum of the Ural Mountains, with much of the gold of Australia and California, and with some of the tin in Cornwall. This case, also, needs no special consideration, because the metal has simply been derived from the denudation of rocks containing metalliferous veins, and in other respects these deposits resemble ordinary superficial accumulations.

3. Most of the metallic ores occur, solely or chiefly, in what are called *veins* or *lodes.* A vein or lode may be defined as being a more or less highly-inclined fissure in the crust of the earth, which has been subsequently filled with foreign matter, this usually consisting of various spars or crystalline substances, more or less impregnated with metals in a native state, or in the condition of ore.

That mineral veins or lodes are in reality *faults,* filled up subsequently by extraneous material, can be proved, in the great majority of instances, by the fact that the beds on the two sides of the lode do not correspond with one another, by

the frequent occurrence of "slickensides," and by the fact that, when veins cross one another, one very generally displaces the other (Fig. 220), or produces an apparent lateral shift at the surface.

The materials contained in veins differ immensely in different veins, and often in different parts of the same vein. As a rule, the bulk of the vein is made up of some generally useless, crystalline matters, such as quartz, calc-spar, heavy spar, etc., these constituting what miners call the "vein-stuff" or "gangue." The metallic substances are mostly disseminated through the vein-stuff as small grains or crystals, or as little nests or strings, or sometimes in considerable masses.

As to the mode of deposition of metals in veins, several theories are held, and perhaps no one of them will apply to all cases. As a general rule, it would appear that the contents of veins have been deposited in the primitive fissure by precipitation from a watery solution. This is certainly the case with the crystalline vein-stuff, and would seem also to be the case with the metals, whether these are native or in the state of ore. In judging

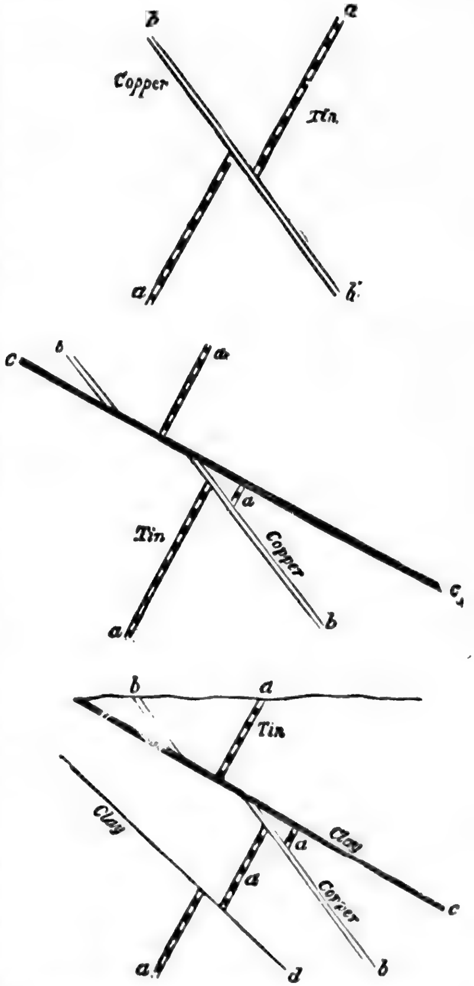


FIG. 220.—Vertical section, showing a copper lode (*b*, *b*,) intersecting a tin lode (*a*, *a*), and producing a vertical displacement or "shift" of the vein.

of this question we must not, of course, consider the solvent power of water as we see it at the surface. When under enormous pressure, and charged with various chemical ingredients, water may be raised to a very high temperature, and might then be capable of dissolving any of the metals. This view is further strongly supported by the phenomena of hot springs. These can generally be proved to break out along lines of fault or fissures in the crust of the earth. They contain most of the materials which are found in veins, especially flint, carbonate of lime, fluor-spar (fluoride of calcium), and heavy-spar (sulphate of barytes), all of which are found commonly in vein-stuff, either alone or associated with one another. Any fissure, therefore, occupied by a hot spring, would doubtless be converted in the course of time into a mineral vein; and there is reason to believe that this has not uncommonly been the case.

With regard to the age of veins, since they are undoubtedly in most cases connected with faults and fissures in the crust of the earth, it is pretty certain that they must be of all ages, and are doubtless in process of formation at the present day. It is very difficult, however, to point to the age of any particular lode, except under special circumstances, such as the occurrence of organic remains in the vein-stuff. In all cases, however, if the lode has been a line of fault, it must be of later age than the strata which it traverses, though it may be impossible to say how much later.

QUESTIONS.

1. OBJECTS and scope of physical geography, of palæontology, of mineralogy, of geology proper?
2. What is the figure of the earth, and what conclusion may be deduced from this?
3. Length of the polar and equatorial diameters of the earth?
4. Most generally accepted hypothesis as to the original condition of the globe?
5. What facts support the view that the interior of the earth is highly heated?
6. What is the general rate of increased temperature in mines and Artesian wells in descending below the surface?
7. What is meant by "mean density," and what is the mean density of the earth?
8. What is the mean density of rock?
9. What conclusion seems deducible from the difference in the mean density of the earth as compared with that of rock in general?
10. What is the ordinary belief as to the condition of the interior of the earth?
11. What is the origin of dry land?
12. Mention instances in which it has been shown that portions of the earth are at present sinking or rising.
13. What is the difference between the northern and southern hemispheres as regards the distribution of dry land?
14. What is the general difference between the Old World and the New, as regards their great mountain-chains?
15. Chief kinds of mountains?
16. Mountains of circumdenudation, how produced?
17. Mountains of uptilting, how produced?
18. What mountains come under the head of "mountains of ejection?"
19. Define a volcano.
20. Difference between submarine and subaërial volcanoes?
21. What is the general appearance of a quiescent volcano?
22. What are the conditions of volcanic activity?
23. Why do earthquake-shocks usually precede an eruption?
24. General phenomena of a volcanic eruption?
25. Nature of volcanic ashes, of scoriæ, of lava?
26. What is the consistence of lava, and its general rate of movement?
27. Chief theatres of volcanic activity at the present day?

28. What two great laws are deducible from the present distribution of volcanoes?
29. What is indicated by the arrangement of volcanoes in lines?
30. General structure of a volcanic cone?
31. Arrangement of the beds of ash and lava round the crater?
32. Dikes, their nature and mode of production?
33. What is the generally-accepted theory as to the causes of volcanic activity?
34. General phenomena of earthquakes?
35. Where are earthquakes most common?
36. What are earthquake-waves, and how are they caused?
37. How are valleys produced?
38. Define "denudation."
39. What are the chief denuding agents?
40. Double action of rain as a denuding agent?
41. What rocks are chiefly affected by rain, and why?
42. How do rivers act as denuding agents?
43. On what conditions does the denuding power of a river chiefly depend?
44. Proofs that rivers really wear away the rocks over which they flow?
45. What is shown by the occurrence of rounded blocks, gravel, and sand, in a river-bed?
46. Mention approximately the amount of solid matter brought down by some of the great rivers of the earth?
47. What is a delta?
48. Mention some of the largest and most important river-deltas?
49. What does the existence of a delta prove?
50. Why should some large rivers not produce deltas?
51. General action of the sea as a denuding agent?
52. Mention some proofs that the sea wears away the coast?
53. What is the essential difference between the action of the sea as a denuding agent and that of rivers?
54. What conclusion may be drawn as to many inland cliffs and precipices?
55. Show, from the phenomena of rivers and the sea, that denudation is a process of *rearrangement*, and not of *destruction*.
56. What is the "line of perpetual snow?"
57. What is the height of this line in Britain, in the Alps, in the Andes, in Greenland?
58. What is a "glacier," and how is it formed?
59. Rate of movement of a glacier?
60. Why does a glacier ultimately cease to advance?
61. What are the "lateral moraines" of a glacier?
62. How is a "median moraine" formed?
63. What is a "terminal moraine?"
64. What is the structure and appearance of a terminal moraine?
65. How would you recognize the terminal moraine of a glacier, supposing the glacier to have disappeared?
66. What are "striated" blocks, and how are they produced?
67. What phenomena would be presented by the bed of a glacier, supposing the glacier to have disappeared?
68. What are crevasses?
69. What are "roches moutonnées?"
70. What are "perched blocks?"
71. What are "erratics?"

72. Whence are the erratics of a glacier derived?
73. What is the present condition of Greenland?
74. How are icebergs produced?
75. What is "continental ice?"
76. How do icebergs come to transport rocks and soil?
77. How may the erratics carried by icebergs be generally distinguished from those transported by glaciers?
78. What may be the size of a large iceberg?
79. What is "weathering?"
80. What rocks weather most readily?
81. What are "subaërial" rocks? Mention examples.
82. What are organically-formed rocks? Mention examples.
83. What are coral-reefs?
84. What are the chief forms of coral-reefs, and how are they produced?
85. What is "coral-rock?"
86. What is "peat?"
87. Explain the doctrines of the "catastrophists" and "uniformitarians?"
88. What is meant by the doctrine of the "adequacy of existing causes?"
89. What is meant by the "crust of the earth?"
90. Has the earth's crust been formed at once, as we now find it, or at successive periods and gradually?
91. How is "rock" defined?
92. What are the four great classes of rocks?
93. By what other terms are aqueous rocks known?
94. How are the aqueous rocks distinguished?
95. What is meant by the term "stratified?"
96. What may be inferred as to the origin of the stratified rocks?
97. How could you distinguish between beds deposited in fresh water, and those laid down in the sea?
98. Define the term "fossil."
99. Do fossiliferous beds contain fossils throughout?
100. Define the term "formation."
101. What is meant by the term "laminated?"
102. Mention cases in which rocks are laminated, and may contain fossils, and yet not be of aqueous origin.
103. What rocks are included under the head of volcanic rocks?
104. How are the volcanic rocks distinguished?
105. What are the Trappean rocks?
106. How would you prove that the Trappean rocks are of volcanic origin?
107. Why should we not be surprised at not being able to point to the cones and craters of the Trappean rocks?
108. What are the Plutonic rocks?
109. How are they distinguished from the aqueous rocks? from the volcanic rocks?
110. How is crystallization affected by rapid or slow cooling?
111. How does this bear on the question of the origin of the Plutonic rocks?
112. Why are the Plutonic rocks called "underlying rocks?"
113. How can it be shown that the Plutonic rocks must have been at one time melted?
114. What general conclusions may be drawn as to the origin of the Plutonic rocks?

115. What are the Metamorphic rocks?
116. How do they agree with the Plutonic rocks?
117. In what do they differ from the Plutonic rocks?
118. What is the ordinary theory as to the nature of the Metamorphic rocks?
119. What is understood by the term "hypogene?"
120. What are the main subdivisions of the aqueous rocks?
121. What is meant by "derivative" rocks?
122. Composition of the arenaceous rocks?
123. What is a "grit?"
124. How are siliceous rocks recognized in the field?
125. What is a conglomerate?
126. What caution must be observed in determining the age of a conglomerate from its fossils?
127. What is a "breccia?"
128. Composition of the argillaceous rocks?
129. What is clay?
130. How are argillaceous rocks recognized in the field?
131. Mention the chief varieties of the argillaceous rocks?
132. What is loam?
133. What is "marl?"
134. What rocks may be said to be chemically formed?
135. Composition and characters of chalk?
136. Characters of limestone?
137. Various modes in which limestone may be produced?
138. Chief varieties of limestone?
139. What is marble?
140. What is an "oolitic" limestone?
141. Characters of magnesian limestone and its chemical composition?
142. How may limestone be recognized in the field?
143. What is gypsum, and how does it generally occur?
144. What is alabaster?
145. How does rock-salt usually occur?
146. Chemical composition of coal, and its chief varieties?
147. In what two forms do volcanic and Trappean formations occur?
148. Is there any chemical difference between the melted products of volcanoes and their mechanical accompaniments?
149. Of what two families of minerals are the volcanic and Trappean rocks essentially composed?
150. Chemical composition of felspar?
151. Leading varieties of felspar?
152. Chemical composition of hornblende?
153. What relations subsist between hornblende and augite?
154. Chief varieties of lavas?
155. What is a "trachyte?"
156. What is obsidian?
157. Chief mechanical accompaniments of modern volcanoes?
158. Chief divisions of the Trappean rocks?
159. What is basalt?
160. What are the mechanical accompaniments of traps?
161. Define the term "porphyritic."
162. What is an "amygdaloid," and how is it produced?
163. Chief varieties of the Plutonic rocks?
164. Chemical composition of granite?

165. How does the quartz of granite ordinarily occur?
166. Chemical composition of mica?
167. What peculiarity is there in the crystallization of granite?
168. To what conclusion as to the origin of granite does this peculiarity point?
169. What is the composition of syenite, of protogine?
170. What is eurite?
171. What are the chief varieties of the Metamorphic rocks?
172. Composition and structure of gneiss?
173. Composition of hornblende-schist, of mica-schist?
174. Nature of quartzite?
175. What are the "divisional planes" of rocks?
176. Define "planes of deposition."
177. What are the differences between "strata" and "laminæ?"
178. What are "joints?"
179. Can any regular arrangement be traced in joints?
180. What are the causes of joints?
181. In what rocks is columnar jointing seen?
182. What is the structure of "articulated" columnar basalt?
183. What law do the columns of an igneous rock always obey?
184. What is columnar jointing due to?
185. Define cleavage, and distinguish it from lamination and jointing.
186. What is meant by the expression that cleavage is a "superinduced" structure?
187. How may the lines of bedding be detected in cleaved rocks?
188. Define "slate," and distinguish it from "shale?"
189. What relation do cleavage-planes hold to the original lines of lamination?
190. How is the texture of cleaved rocks affected by the cleavage?
191. What is the effect of cleavage upon fossils?
192. What is the generally-accepted theory as to the origin of cleavage?
193. Mention the experiments of Sorby and Tyndall?
194. Define "foliation."
195. Define "schist," and distinguish it from slate and shale.
196. Mention any theory as to the cause of foliation.
197. Is there any necessary relation between the planes of foliation and those of deposition?
198. In what position were the stratified rocks originally deposited?
199. In what position are stratified rocks now usually found?
200. What is the cause of "inclined" strata?
201. What is meant by "thinning out?"
202. What is meant by "false bedding?"
203. What does this indicate?
204. Explain the formation of ripple-mark.
205. What are "desiccation-cracks," and how are they formed?
206. What do "rain-prints" indicate?
207. What is meant by the "dip" of inclined beds?
208. Define "outcrop."
209. What is the "line of strike?"
210. What necessary relation subsists between the strike and dip of inclined beds?
211. What beds have no "line of strike?"
212. What inclined beds have no "point of dip?"
213. What is understood by "contorted" strata?

214. How are contortions produced?
215. What is an anticlinal curve?
216. What position is held by the oldest beds in an anticline?
217. What is meant by a "quâ-quâ-versal" dip?
218. What is a synclinal curve?
219. What position is held by the oldest beds in a synclinal curve?
220. When do beds form a "basin?"
221. When are strata said to be "conformable?"
222. Define unconformability.
223. Does unconformability necessarily indicate a discordance in dip?
224. What is the commonest case of unconformability in practice?
225. What sequence of phenomena is indicated by unconformability?
226. What is "overlap?"
227. Is overlap always a sign of unconformability?
228. What is a fault?
229. What is meant by the "throw" of a fault?
230. Explain the terms "up-throw side," "down-throw side."
231. What is the "hade" of a fault?
232. In what direction does a fault necessarily hade, and why?
233. What is "slickensides?"
234. What is the ordinary condition of the up-throw side of a fault?
235. How are faults ordinarily detected in practice?
236. What is meant by the "lateral shift" of faulted and inclined strata?
237. How does the repetition of the same beds as produced by faults differ from that produced by anticlinal and synclinal curves respectively?
238. What are the chief tests of the age of any particular bed or set of beds?
239. In what way and to what extent do fossils enable us to pronounce as to the age of any given bed or set of beds?
240. Mention some reasons why no country exhibits a complete and regular succession of the aqueous rocks?
241. Into what three great periods is the entire series of fossiliferous rocks divided?
242. What are the great divisions of the animal kingdom?
243. Give the characters of the *Protozoa*, and their chief fossil representatives.
244. Characters and chief fossil groups of the *Cœlenterata?*
245. Characters and more important extinct forms of the *Echinodermata?*
246. Characters and chief fossil forms of the *Annulosa?*
247. Characters of the *Mollusca?* Leading groups of the same?
248. Characters of the *Vertebrata?*
249. Leading groups of the Vertebrates?
250. Main divisions of the vegetable kingdom?
251. Name "Laurentian," how derived?
252. Where are the Laurentian rocks chiefly developed?
253. Mineral characters of the Laurentian rocks?
254. Life of the Laurentian period?
255. Relation of Lower to Upper Laurentian?
256. Where are the Huronian rocks found?
257. Mineral characters and age of the Huronian rocks?
258. Their relations with the Laurentian rocks?
259. Name "Cambrian," how derived?
260. Mention the chief members of the Cambrian series in Britain.
261. Give the chief fossils of the Lingula flags.

262. What are Trilobites?
263. Chief Cambrian rocks of North America?
264. What fossils specially characterize the Skiddaw and Quebec groups?
265. Mention some of the Cambrian rocks of the continent of Europe.
266. What classes of animals chiefly abounded in the Cambrian period?
267. Name "Silurian," how derived?
268. Main divisions of the Silurian series and chief localities in which it is developed?
269. Chief subdivisions of the Lower Silurian series in Britain?
270. Mineral characters, thickness, and fossils, of the Bala group?
271. Chief subdivisions of the Upper Silurians in Britain?
272. At what horizon are the earliest fish-remains found in Britain?
273. Chief subdivisions of the Lower Silurians in North America?
274. Chief subdivisions of the Upper Silurians in North America?
275. Chief classes of animals which flourished in the Silurian period?
276. Origin of the name "Devonian?"
277. How far can the name "Devonian" be regarded as equivalent to "Old Red Sandstone?"
278. Divisions of the Old Red Sandstone in Scotland?
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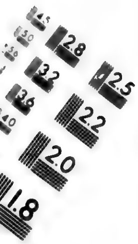
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